EPIDURAL ANESTHESIA: NEW COMPUTER TECHNOLOGY USED TO ENHANCE THE TEACHING OF A COMMON ANESTHETIC PROCEDURE

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ABSTRACT

The epidural anesthetic procedure is one of the most commonly used techniques in anesthesia. Its usefulness during labor, general surgery and for post-operative pain control is well documented. The underlying anatomy and technical skills for administering an epidural anesthetic have traditionally been taught using lectures, books, models and human materials. There are also Computer-Assisted Instruction (CAI) CD-ROMS being developed to teach regional anesthesia. Because of rapidly advancing technology, it has recently become possible to use computers to re-create actual human anatomy by extracting data from frozen serial sections, CT and MRI scans. One way this was done was by digitizing this data from a human male and female.

The National Library of Medicine originally conceived the Visible Human ™ (VH) Project in 1986. Its initial goal was to acquire CT, MRI, and cryosections from a representative male and female specimen, in approximately one-millimeter intervals. A complete male and female were scanned and digitized but have only been available since 1995. This dataset is now available for review and manipulation to licensed individuals and institutions. High-end computers can now take this digital data and re-create the anatomical structures in a three-dimensional format. This new information can be used to generate 3-D computer models of specific regions of the body.

We have developed teaching photographs and three-dimensional images to enhance the learning of epidural and spinal anesthetic anatomy and procedures. This includes a description of commonly used equipment such as needles and catheters. Also, sections of the Visible Human ™ lumbosacral region and spinal canal were downloaded and displayed in cross-section, sagittal and parasagittal planes. Structures such as the vertebrae, ligaments, spinal cord and meninges were then labeled in order to train anesthetists in the basic anatomic landmarks. The lumbosacral region of the VH dataset was then volume rendered using high-tech computers and a high-end software package called Analyze ™. The result of the volume rendering was the creation of three-dimensional objects, which can be identified with labels, and manipulated by the learner.

EPIDURAL ANESTHESIA: NEW COMPUTER TECHNOLOGY
USED TO ENHANCE THE TEACHING OF A
COMMON ANESTHETIC PROCEDURE

By

David C. Olsen, LT, NC, USN

THESIS

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DEDICATION

To the most important people in my life, I dedicate the creation of this thesis. Without their love, encouragement and support the attainment of a dream and the creation of this thesis would not have been possible.

I wish to thank my parents for instilling in me a strong work ethic and the desire to strive for further education and knowledge.

To my wife and children, I dedicate this paper and thank you for understanding and supporting my quest for knowledge, and for your many years of love and encouragement.

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CHAPTER ONE: INTRODUCTION

Background

Current improvements and the decreasing costs of computer technology have made the use of the computer commonplace and has allowed the medical community to integrate computers into the educational process of medicine and surgery (Satava, 1994). Education using Computer Aided Instruction (CAI) is common in many schools and should be incorporated into the curriculum of anatomy teaching institutions (Educational Affairs Committee, 1996). Virtual reality, though relatively new as entertainment to the general public, has been researched and utilized in industry since the 1950s (Pimentel & Teixeira, 1995).

Expanding amounts of scientific knowledge in the field of medicine lends itself well to the massive storage capabilities and data manipulation capabilities of modern computers (Ota et al., 1995). Many medical texts are already available on CD-ROM while current nursing texts on CD are in publication. Many of the features of having this information compiled in this way include teaching and testing of biological and medical sciences (Burt, 1995), pharmacology (Pimentel & Teixeira, 1995) and anatomy (Dunkley, 1994).

Human anatomy has been taught after Vesalius using several methods. Students have learned by reading texts, studying models, posters and drawings, dissecting cadavers in laboratories, and interacting with live patients (Duncum, 1947). These methods, though satisfactory, can require a tremendous amount of time and expense. The use of current technology may save time and expense which may provide the opportunity for a wider audience to gain access to this information.

A most innovative method of teaching anatomy is through the use of computer-generated visual models generated from a human male and female, currently called the "Visible Human ™" (National Library of Medicine, 1990). Dr. Donald A.B. Lindberg, MD, Director, National Library of Medicine (NLM) stated recently, that "the public will get a look at how the world's first computerized cadavers'--referred to as the Visible Human ™ Male and the Visible Human ™ Female--are beginning to revolutionize how anatomy is taught and medicine is practiced in the United States and throughout the world" (Lindberg, 1996). The data from the Visible Human ™ Male (VHM) and the Visible Human ™ Female (VHF), can be virtually rendered into three-dimensional objects, and can provide information to the user that would not be seen in two-dimensional graphics. The computer-generated models can be visualized on a computer monitor by rotating the objects in virtual space so the user has access to all dimensions of the item. The student can also assemble and disassemble the components of the object much as is done in a jigsaw puzzle. The items can be identified and labeled, and the user can be quizzed about the components that he or she has just learned.

There are potential hazards to the patient while including them in the teaching of certain medical procedures such as surgery or regional anesthesia. These procedures may now be taught virtually without any risk to the patient. Modern pioneers of virtual reality are already using this technology to teach surgical techniques (Dumay, 1995, Robb, 1996), endoscopic procedures (Robb, 1996), (Kaufman & Hong, 1996), and even epidural anesthesia (Ohio Supercomputer Center, 1996).

Anesthesia texts that have been written for computers are available for purchase or for viewing on the World Wide Web (WWW). The World Wide Web is a network of

computers linked to the internet that provide graphical "pages" of text and pictures that relate to many subjects. There are also compact computer programs that can be used in palmtop or laptop computers for quick and ready references that can be used either at home or in the operating theater (Pinciroli & Valenza, 1995). The World Wide Web encompasses a global network of computers that carry information in "cyberspace" that is specifically tailored for the anesthesia community. This information is related to the study and practice of anesthesia, and is free for public access. Found on some of these web sites are programs in which the authors have attempted to render real human data into virtual anatomical models, and include the trachea and bronchial tree, abdominal cavity, skeleton, musculature, brain and heart. Also available on the Internet is computer software that is specifically designed for reconstruction of data into 3-dimensional models (Sausville, 1996), (appendix D). This software ranges in cost from free and without support to expensive which includes technical support. With all these new available resources the opportunities for growth in the field of anesthesia education appear to be limitless.

Interactive 3-D Graphics and Virtual Reality in Anesthesia

Anesthesia is a practice that has used high-technology devices for some time (Weghorst, 1994). The most up-to-date medical monitoring equipment, though not necessary, is used to help assist the anesthesia provider by monitoring vital signs, inhaled anesthetic agents, and exhaled vapors. Medical equipment companies have been refining these devices for many years, but have not been particularly interested in developing new features. There are several new devices and technologies available in the anesthesia

community, developed mostly by the user or anesthesia provider with some computer expertise. A Heads-Up Display (HUD) has been designed so the anesthesia provider can have immediate access to vital digital information through virtual glasses, while not having to look away from the patient. An Intravenous (IV) simulator was developed by High Techsplanations, of Rockville, Maryland (High Techsplanations Inc., 1996), which allowed the trainee to use a virtual arm for venipuncture practice while using a *haptic* or tactile feedback-generating needle attached to the computer. They have developed several other simulations as well (appendix F). Also available are simulators that provide a virtual fly-through of the tracheobronchial tree (Sausville, 1996), a virtual endoscopy (Robb, 1996), and a virtual demonstration of a celiac plexus block (Sausville, 1996). There is also a virtual epidural needle placement simulator (Ohio Supercomputer Center, 1996). The most recent attempt at virtual instruction in anesthesia, is the Anesthesia Simulator (CAE inc., 1996). This computer controlled "patient" is draped and prepared in an operating room setting, similar to a real patient. Any action on the part of the anesthesia provider is detected by the mannequin's sensors, fed to a central computer, which provides realistic feedback to the provider through visual cues, changes in vital signs, or any of the many parameters that are checked during an anesthetic. The provider is totally immersed in the operating room experience, and gains valuable lessons through realistic drama. The Anesthesia Simulator was expensive and this may limit its availability to the end user.

History of Epidural Anesthesia

Soon after the first uses of inhalational agents for anesthesia in the mid -1840s, the hypodermic syringe was invented independently by Pravez in 1851 and Wood in 1853 (Duncum, 1947). Opioids had just been considered for pre-anesthetics, but were not in the favor of medical men at the time. In 1855, Alexander Wood, a surgeon, proposed "a new method of treating neuralgia by the direct application of opiates to the painful points." This was first attempted topically and then with the use of acupuncture needles, but with no relief of pain. He remembered that earlier in his practice he had removed a nevus with the injection of an acid solution under the skin using a syringe made by Mr. Ferguson of Giltspur Street, London. He obtained one of these syringes for the purpose of injecting the morphine closer to the affected nerve of a patient suffering from neuralgia. This was the first recorded case of an analgesic injected using a needle. Wood's use of morphine for neuralgia soon became common practice.

In 1859, cocaine had been isolated from the Erythroxylon coca plant by Neimann (Duncum, 1947), but it was not until 1884 that Koeller placed a drop of cocaine solution into the eye of a frog and then a guinea pig, and reported that cocaine had anesthetic properties. William Stewart Halstead conducted the first experiments in "nerve blocking" (Duncum). He injected a cocaine solution into a sensory nerve trunk and produced anesthesia in the region of its peripheral distribution. He then blocked the roots of the brachial plexus in the neck of another patient, then, being a surgeon, successfully operated on him. This was the first known regional anesthetic. The first spinal type of anesthetic was performed by J. Leonard Corning (Duncum) in 1885 after initial experimentation on dogs. He injected a cocaine solution into the "space situated between

the eleventh and twelfth dorsal vertebrae" in a patient with spinal weakness and seminal incontinence. After several injections, the patient stated that his legs "felt sleepy." Corning noted that there was diminished sensation and reflex action in the legs when stimulated with "the wire brush attached to a faradic battery" (Duncum). The drug had been placed extradurally, making this the first reported case of an epidural anesthetic.

Many experiments followed Corning's successful epidural anesthetic, but it wasn't until 1899 that August Bier reported six successful operations he had performed on patients while under a low spinal block. By the 1900's many surgeons, like Tuffier in Paris, and Matas in New Orleans, were operating on patients with spinal anesthetics. Spinal and epidural anesthetics were becoming a common practice and became more refined with the invention of better needles and newer drugs (Bankert, 1993).

Anatomy and Regional Education

Teaching spinal and epidural anesthesia started from the hands of the surgeons who first performed the procedures to those who were willing to experiment. Those with the most experience taught the techniques in a hands-on fashion. Anatomy had been taught in the same way, as well as by cadaver dissection, though that was not publicly appreciated. Anatomy has also been taught in medical schools with textbooks that date back to the days of Hippocrates. Many drawings were done by Leonardo DaVinci and Vesalius (Saunders, 1950), both of whom dissected cadavers. These drawings and the drawings of Frank Netter (Netter, 1989) are still in use today. Other methods of teaching include the use of models. Though some are made from real bone, most are plastic, unrealistic, and expensive. These can be effectively used to teach anatomy and epidural

procedures, but not every student of medicine has access to this type of equipment. Cadavers are still used in many medical schools for teaching anatomy and regional anesthesia, but poor dissection skills may prevent the student from seeing realistic anatomy, and the lack of flexibility in the cadaver may make regional anatomy unforgiving and unrealistic.

Although millions of anesthetics are provided each year by Certified Registered Nurse Anesthetists (CRNAs), not all anesthetists are trained in regional techniques (Horton, 1993). Thus, the Council on Accreditation of Nurse Anesthesia Educational Programs has begun to "adopt an accreditation requirement for the administration of regional anesthesia by students" (p. 497). Since anesthetists have administered regional anesthetics soon after their inception (Bankert, 1993) it is appropriate that nurse anesthesia students continue to learn not only from practical experience, but with proper didactic courses as well.

Bony Anatomy

Anatomy was learned through the works of Galen, a Greco-Roman physician. Vesalius, a great author and artist of anatomy in the 16th century, included a plate drawn by Galen, of the vertebral column. Vesalius wrote in one of his many letters that Galen was "the prince of physicians and preceptor of all" (Saunders, 1950). Many stated that Vesalius promoted anti-Galenism in his anatomical teachings and drawings, however, Vesalius himself stated that he knew of such rumors. He didn't so much disagree with the teachings of Galen, as he found differences in the anatomy through observation and was merely trying to correct or rectify what he found to be in error (p. 13). Through the use of

advanced technology, differences in anatomical structure are still being noticed and described, not in an attempt to be anti-Galenistic, but only to "seek corroboration and note discrepancies by the observational method" (p. 13). Some of the differences found with modern equipment are described.

The bony structure of the vertebral column serves to protect one portion of the central nervous system, the spinal cord. It is composed of seven cervical, 12 thoracic, 5 lumbar, 5 sacral and 4 coccygeal vertebrae. The most prominent of the spinous processes is on the 7th cervical vertebrae (C7), which is palpable from the posterior side. The cervical vertebrae are smaller and provide less structure for weight bearing. The spinous processes in the lumbar region are shorter and broader than in the mid-thoracic region. They are designed to handle much more weight. Spinous processes are angulated to some degree in the T3-L1 section, but mostly in the area of T4 to T9. The first two thoracic and second through fourth lumbar spinous processes lie immediately above their respective vertebral bodies.

Landmarks

The inferior aspect of the scapula is opposite the 7th thoracic vertebra, and Tuffier's line, or the line between the iliac crests is usually at the level of the 4th to 5th lumbar disk. These landmarks are roughly 50% accurate due to natural variability of the anatomy (Brown, 1996). The vertebral foramen, the canal for the spinal cord, is formed by back vertebral bone. The vertebral laminae and pedicles form the lateral borders of the vertebral foramen. The vertebral body forms the anterior border of the canal, and the vertebral arch, composed of two pedicles and two laminae form the posterior border. The

junction of the pedicles and laminae forms the transverse processes. The union of two opposing laminae forms the spinous processes.

Ligaments

The vertebrae are attached to each other by either long or short ligaments. The anterior and posterior longitudinal ligaments are continuous structures giving support from C2 to the sacrum. Between the vertebral bodies lie intervertebral discs that are composed of a tough outer ring called the annulus fibrosis and a softer center portion known as the nucleus pulposus. The supraspinous ligament is a tough fibrous structure that extends from C7 to the sacrum that connects the posterior surfaces of the spinous processes. It becomes wider and stronger in the lower part of the spinal column. The interspinous ligament connects the spinous processes of adjacent vertebrae. It also becomes stronger and thicker in the lumbar region. Attached to the anterior surface of the laminae above and the posterior surface of the laminae below is the ligamentum flavum. It extends from the articular processes laterally to the posterior midline and is thickest in the lumbar region.

Spinal Meninges

Three layers of tissue known as the pia mater, the arachnoid mater and the dura mater surround the spinal cord. The pia mater is the innermost layer and is integrally attached to the spinal cord. The arachnoid mater lies outside the pia mater and the space that is formed between them is filled with cerebrospinal fluid. The dura mater is the outermost of the three layers. It is continuous with the inner meningeal layer of the intracranial dura. In the average adult, the dura starts at the foramen magnum at the base

of the skull, and continues as a sac surrounding the spinal cord and neural contents to the middle body of the 2nd sacral vertebrae. There are 40-50% of the population that may have an extension of the dura further caudad (Katz, 1994). The dura then tapers and is connected to the periosteal surface of the coccyx.

Vertebral Dimensions

There are several changes in dimensions of the vertebrae themselves based on the region. In the cervical and lumbar regions, the canal is shaped as a triangle, but in the thoracic region, the canal is circular. The spinal canal varies in its internal dimensions (Brown, 1996). In the cervical canal, the width between the pedicles expands to 25mm, narrows to 22 mm at the level of L-1, and then expands again to about 27 mm at L-5. The anteroposterior dimensions of the canal remain fairly constant at 15-16 mm throughout the vertebral column.

Epidural Space

Local anesthetic agents placed into the epidural space through a needle or catheter constitutes an epidural anesthetic. Spinal and epidural anesthesia are considered "two of the most popular regional anesthetic procedures employed for surgery, obstetrics and postoperative analgesia" (Barash et al., 1992). It is imperative that the student or practitioner of this anesthetic procedure be intimately familiar with the bony anatomy of the vertebral column, the ligaments that provide support and the spinal canal with its contents.

The space between the ligamentum flavum and the dura is known as the epidural space (Barash et al., 1992). It normally contains a loose type of connective tissue, loose

fat and blood vessels. There is also a rich venous plexus that is contained within the epidural space, but there is normally no free fluid found. Many texts depict the epidural space as a continuous space of uniform width, that completely surrounds the dura, however, cytomicrotome sections and in vivo imaging (CT, MRI) have shown the epidural space to be an empty, potential space (Brown, 1996). The size of the epidural space varies inversely with the content of the spinal cord (Katz, 1994). The spinal cord generally ends at the interspace of L2 but the dural sac extends further caudad. The epidural space widens laterally after the termination of the spinal cord. The epidural space is smaller in the cervical and lumbar areas due to widening or enlargement of the cord. The widening that occurs is due to added nerve fibers that supply the upper and lower extremities (Katz, 1994). The middle lumbar vertebral canal widens laterally where the dura contacts bone and ligament. This region is filled mostly by the dural sac. The epidural contents are contained in "discontinuous segments" (Brown, 1996, p. 55) separated by areas where the dura touches the canal wall. These discontinuous segments have been shown using computer 3-D reconstructions of MRIs taken from live patients (Brown, 1996). This is illustrated in figures 19 and 20. Figure 19 shows no epidural space between the ligamentum flavum and the dura. The epidural space is visible in figure 20. The anterior epidural compartment is separated from the rest of the vertebral canal that stretches from the posterior longitudinal ligament (PLL) laterally. Superior to the L4-5 disc each one of the "discontinuous segments" of the epidural space ends at the level of each disc as it attaches to the PLL. This separates each segment from the one above and below. Inferior to the L4-5 disc, the epidural space widens, and the fat content increases as the dural sac size decreases. This may account for the difficulty blocking the L5 and

sacral nerve roots during an epidural anesthetic, since the anesthetic agent is not held in close proximity to the nerve roots as it is in other areas.

Several distances have been measured in the epidural space (Katz, 1994). In the lumbar region, more specifically from L2 inferiorly, the epidural space measured from the ligamentum flavum to the dura is 5-7 mm while in the mid-thoracic area, the distance is 3-5 mm. The lower cervical region has the smallest epidural distance at 2 mm or less, and at C7, the site for cervical epidural or spinal anesthesia, the distance is usually 4 mm.

Table I: Epidural Distances Between Ligamentum Flavum and Dura

Region of Spinal Column	**Distance**
Cervical Vertebrae	2 mm
7^{th} Cervical Vertebrae	4 mm
Mid-Thoracic Vertebrae	3-5 mm
Lumbar Vertebrae	5-7 mm

As mentioned before, the epidural space contains a loose type of fat. The amount of fat in the space is proportional to that of other body fat. Epidural fat is mostly free-floating though it has some connective tissue septa present in the more organized fat lobules. In children, the fat seems to be more unorganized, while the fat is denser in adults. This may be one of the reasons for the ease of epidural catheter passage in children (Katz, 1994). This information is important because it may help the practitioner decide which type of epidural needle or catheter to choose.

Epidural Needles and Catheters

There are several types of needles used to administer an epidural anesthetic in adults (Katz, 1994). The most commonly used types are the Tuohy and Hustead types, sized at 17 or 18 gauge. These needles are disposable and are unique because of the curved tip and blunt bevel designed to resist accidental dural puncture (Barash, 1992). The stylette that rests inside the needle is flattened to match the bevel of the needle, which is slightly shorter in the Hustead type. The Crawford needle has no curved tip, but has a short bevel (b-type). This is advantageous for use in single shot anesthetics such as epidural steroid injections. Also available, but not used much is a generic 18 gauge curved tip needle, similar to the Tuohy needle.

Catheters come in several styles and are usually packaged with the needle into which they are designed to fit. They are generally made from non-reactive silicone, nylon or polyurethane. They are often marked with measurements in centimeters, to aid in the placement of the catheter into the epidural space. Two types of outlet hole patterns are predominant. A single outlet hole at the end of the catheter is chosen for use when all the anesthetic solution needs to be placed in a known or presumed location. There are multiple hole-tipped catheters as well, which allow for a greater spread of anesthetic solution within the epidural space. Catheters also vary in stiffness, and whether an internal stylette is present or not.

Epidural Needle Insertion Technique

There are several methods of introducing the epidural needle into the epidural space, but the "loss-of-resistance" technique is the most common method used (Barash, 1994). Drawing an imaginary line between the iliac crests identifies the location of the

4th lumbar vertebrae. Usually the L2-3 or L3-4 interspace is used for the procedure. After the skin is prepared in a sterile fashion and the skin is injected with a local anesthetic, the epidural needle with stylette is inserted 1-2 cm. The loss-of-resistance technique is done using either 1-2 cc of air or saline in a sterile syringe. The syringe is attached to the epidural needle after the stylette is removed. As the needle is advanced, a constant pressure is applied to the syringe. The needle passes between the spinous processes of the vertebrae, then through the skin, subcutaneous fat, supraspinous ligament, interspinous ligament, ligamentum flavum then into the epidural space. At this point, the resistance felt against the plunger of the syringe is "lost" and the plunger moves forward. It is at this point that a test dose of anesthetic or epidural catheter can be placed. If at any point the needle moves further inward, the dura may be pierced and cerebrospinal fluid (CSF) will drip from the needle. This is the location of proper placement of a spinal needle during a spinal or intrathecal anesthetic. Knowledge of the anatomy of this region is essential to the success of the epidural or spinal anesthetic.

Indications for Use of an Epidural Anesthetic

Since the development and fine-tuning of the epidural technique, the indications for usage have narrowed considerably (Katz, 1994). Those performed in the lumbar region are most commonly used for surgical procedures below the diaphragm. Although a common use of the epidural anesthetic technique is for control of post-operative pain, it is often used for diagnosis and treatment of a variety of acute and chronic painful conditions. In cases where a prolonged sympathetic block or somatic nerve block is needed, it is easily accomplished with an epidural catheter in place. This is commonly

used during labor. With the properly chosen anesthetic solution, somatic pain can be attenuated while leaving motor function intact. Thoracic epidurals have been used most often for pain management of post-thoracotomy pain, broken ribs and flail chest. Cervical epidurals are of limited use, but have been used for epidural steroid injections to treat cervical radiculopathies.

Knowledge of the exact procedures for epidural procedures is extremely important for successful anesthetics and is secondary in importance only to the knowledge of the specific anatomical details of the patient. Drawings and photographs have been available and used for many years, but only recently has an information source that can be viewed in exacting detail and manipulated by the user become available to the anesthesia practitioner. This dataset is known as the Visible Human ™.

Visible Human ™ Male Dataset

The Visible Human ™ Male (VHM) dataset was created after finding a suitable male cadaver. A male prisoner, who was sentenced to death by lethal injection, donated his body to science. After his death the body was shipped to the University of Colorado, the primary site of the original segmentation process. CT and MRI scans were then performed throughout the entire body. His body was encased in a special blue gelatin and frozen to minus 160 degrees Fahrenheit. It was then cut into four blocks to make each block a manageable size for the sectioning equipment. The body was then sectioned transversely using a custom made cryogenic macrotome into one-mm sections (N=1878). After each section was made a high-resolution color photograph was taken of that section. Representative cross-sections and figures are listed in Table II. From these sections,

sagittal (fig. 5) and coronal images (figs. 3, 4) were reconstructed on computers. Each color photograph was captured as a 2048 by 1216 digital image in 24-bit color (fig. 7). These images were cataloged so they could be restacked to re-form the human body. CT and MRI images were also taken in approximately one-mm sections. This data can also be re-stacked to construct the human body that is held within its digital images.

Table II: Anatomic Structures with Related Figures and Cross-Section Numbers.

ANATOMIC STRUCTURE	VH MALE FIGURE / CROSS-SECTION #	VH FEMALE FIGURE / CROSS-SECTION #
Reconstructed skin	Fig. 1	Fig. 2
Coronal view	Fig. 3	Fig. 4
Sagittal view	Fig. 5	
Close-up sagittal conus	Fig. 5a	
Close-up sagittal head	Fig. 6	
High-res. color plate	Fig. 7	
Thoracic cross-section	Fig. 8 #1570	Fig. 9 #1560
Conus cross-section	Fig. 10 #1610	Fig. 11 #1585
Iliac crest cross-section	Fig. 12 #1735	Fig. 13 #1705
Lumbar 3-4 cross-section	Fig. 14 #1720	Fig. 16 #1700
Close-up L3-4 cross-section	Fig. 15 #1720	Fig. 17 #1700

Visible Human ™ Female Dataset

The Visible Human ™ Female (VHF) dataset was obtained from the body of a 59-year-old Maryland woman who willed her body to science. The CT data was obtained at near one-mm intervals, the same as the VHM. However, the fresh section data, the high resolution color photographs, was obtained at 0.3 mm intervals throughout the body in contrast to the male fresh sections, that are in 1 mm sections. This indicates that approximately 5000 images were created. As in the VHM data set, the coronal and sagittal sections of the VHF were re-created by computer from compiling the cross-section data.

History of Virtual Reality

Virtual reality was a term first coined by Jaron Lanier, the founder of VPL Research (Burt, 1995). Virtual reality has a broad spectrum of meaning and can't easily be defined in one sentence. It is also known as *artificial reality, cyberspace, virtual environments, virtual presence,* and *telepresence.* It has been explained as "a way to represent and communicate what you can imagine in your mind." It is also identified as "experiencing some event that does not physically exist in the world in front of you" (Pimentel & Teixeira, 1995).

Virtual reality is now being developed for use in Minimally Invasive Surgery (MIS) procedures (Ota et al., 1995). Two-dimensional video is used for laparoscopic procedures, but lacks the sense of depth required to operate on two-dimensional structures. This makes eye-hand coordination difficult to achieve, and training is rigorous. There are currently two types of three-dimensional visualization used in the medical community (Pimentel & Teixeira, 1995). Three-dimensional ultrasound is being used to assess fetal development in vivo. More complex that this however, is the use of CT and MRI data during brain surgery. Three-dimensional images rendered from CT and MRI images can be superimposed over the patient's live anatomy. This provides three-dimensional mapping of lesions or defects, which help pinpoint anatomical locations for the surgeon. CT and MRI data can also be fed into a computer, which will then control robotic structures that will position surgical instruments at the precise location, and at the proper angle for incision or ablation of structures.

It is not yet widely spread, but virtual reality is already being developed and used for the simulation of surgery (Satava, 1994). Several medically directed companies have

developed simulators that simulate the knee and the abdomen. The surgeon uses mouse or glove-driven devices to move surgical instruments to rendered structures where incisions can be made, and results seen. The technology is still primitive, but is improving rapidly (Pimentel & Teixeira, 1995).

There are two existing models of a virtual reality device known as "The Responsive Workbench" (Frohlich et al., 1995), (Rosenblum, 1996). A demonstration provided by the Naval Research Laboratory showed that an entire person was being created virtually. A large table, much like a flat television screen, was used to display the image of a skeleton. Using the most advanced technology, Liquid Crystal Display (LCD) shuttered glasses were worn which brought the lying skeleton to three-dimensional form. Voice commands caused the skeleton to move, rotate, disassemble and reassemble. The most interesting part though, was that the Dataglove had been incorporated into the program. By wearing the glove, the user could reach out and "pick up" a body part, rotate it for closer visual inspection, and return it to its rightful place. This incredible feat was accomplished through computer programming alone. The skeleton, and the few internal organs it had, was created from imaginary data conceived in the programmer's mind. Incorporation of real anatomy data into this device would allow a realistic three-dimensional view of anatomy only imagined before.

Statement of Problem

Nurse anesthetist students and other anesthesia providers need a more cost effective and reality-based mechanism to learn epidural anatomy and regional anesthetic techniques. Students of anesthesia have historically been taught regional anesthesia in a

variety of ways. Many students of anesthesia have used books and models as their way of gaining exposure to regional anesthesia techniques, but this method fails to present the information in a realistic way. Texts are often cumbersome and expensive, and only give a two-dimensional view of three-dimensional anatomy. Models though three-dimensional can be cost-prohibitive to many students, and availability at universities may be limited.

Cadavers have also been used to teach regional anatomy and anesthesia techniques. It is difficult to visualize anatomical structures of human anatomy from a non-compliant or stiff specimen. Anatomical landmarks and intricate structures, such as those found around the spinal column, may also inadvertently be destroyed due to poor dissecting skills.

The research question is: Can a student at the university level create computer-generated, high-resolution images and a three-dimensional model, using the Visible Human ™ dataset, in a cost-effective manner, and use it to enhance the education of regional anesthesia, and what are the procedures for doing so?

Purpose of Study

There are many exciting new opportunities for education in the field of anesthesia. By using the most current, new technology to teach epidural anatomy and procedures for regional anesthetics, a new generation of educational material can be created. The purpose of this endeavor was to create procedures for acquiring, editing and manipulating the Visible Human ™ dataset to create high-resolution color plates. The anatomical structures that are important for teaching epidural anesthesia were identified with labels. In addition, procedures for re-creating three-dimensional anatomical structures from the

two-dimensional VH data were created. Specific regions from the anatomical slices of the Visible Human ™ male or female will be cropped to an appropriate working size. Certain anatomical features such as the lumbar region musculature, vertebrae and spinal canal were outlined, and volume-rendered into three-dimensional objects that can be visualized from all angles.

Significance of Study

The creation of cyber teaching tools that are based on true human anatomy from the Visible Human ™ data has become a new and unique idea in the educational arena. This study may be one of the first presentations of a use of the Visible Human ™ Datasets in the nursing literature. This new tool will be capable of teaching the anatomy of a specific region of the human body to nurse anesthetist students. It can also be used to teach anesthesia residents, university faculty, or as a review tool for those currently in anesthesia practice. Once completed, this project can be placed onto a Compact Disk-Read Only Memory (CD-ROM) for computers, and distributed throughout the anesthesia community, either across the World-Wide-Web, or as a low-cost computer program. This will allow many anesthesia providers to have access quickly, efficiently, and inexpensively to the information they need. It can also be used for the education of other health-care providers such as nurses, physicians, physical therapists and more. Future applications of this include incorporation of the remainder of the human data into educational segments for compilation into one complete educational package. It may then be available to anyone interested, as is the data from the Visible Human ™ Project, developed at the National Institute of Health (NIH).

Current educational trends indicate that most, if not all, medical texts will be available as computer-accessible data. Soon the three-dimensional graphics created during this project may be included with that information, making data retrieval from the operating room, or perhaps a remote location in the combat zone, just a few keystrokes away.

Definition of Terms

Cyberspace- any location within the confines of a computer program or the Internet can be described as 'cyberspace'.

Epidural space- meaning 'around the dura', is the potential or non-existent space surrounding the dura mater. Three layers of protective tissue, the pia mater, arachnoid mater and dura mater, the dura mater being the outermost layer surround the spinal cord. Local anesthetics or other medications can be injected into this space during the administration of regional anesthesia.

Internet- computers worldwide that are connected together to form a network. These individual computers can be connected through dedicated cables or telephone lines, or can be connected from one's home through a standard telephone line. The computers that are connected to the 'net' include many types and forms of information that can be retrieved or reviewed by anybody with a computer that is connected to the Internet.

Regional anesthesia- The practice of injecting a local anesthetic into a specific region of the human body for the purpose of providing analgesia (pain relief).

Rendering- The process of using a computer to gather several sets of two-dimensional data, and compiling them to form a three-dimensional object.

Virtual Reality (VR)- A computer-generated object, picture or environment that is created with the purpose of altering or enhancing reality, in a way which it can't be seen normally. It may be created from reality-based information, or created from ideas that could not be visualized otherwise. It also includes a human-computer interface with which the human can interact with the environment generated by the computer.

World-Wide-Web (WWW)- A subset of computers on the Internet that hold graphically constructed documents for viewing by others on the Internet. A **browser**, a graphic-viewing program specially designed for viewing 'web pages' is used to view these 'pages' which can include colors, designs and pictures. Also included on these pages are **links** that will connect the user to another WWW page either on the same computer, or on another computer anywhere in the world that is connected to the internet.

Summary

Enhanced computer graphics and virtual reality programs have been created to fulfill a desire in man to enhance the reality of real or imagined things. First used for training purposes, this new and exciting technology has been adapted and developed for entertainment as quickly as the demand has grown. Medicine is one profession that has grown slowly from great study and experimentation, and does not take change lightly, but those in the medical community have seen the tremendous potential of computer assistance and visualization for expanding the realms of medical knowledge. This modern technology has quickly been adopted by a few in the medical community, but much of the known medical information has yet to be ported to computer datasets. Anatomy is the foundation of medicine, and having anatomical data readily available on computer would

speed access to this vital information. Regional anesthesia has been performed for many years, and those performing regional techniques have learned anatomy through books, cadavers, and live patients. This kind of learning has been difficult and unrealistic, and included some risk to the patient. Creating an anatomical teaching tool based on human data, and of a specific region, is the next step in the computerization of medical knowledge. The creation of an anatomical model, computer generated from real human information, and used for the education of those in the medical community, and specifically anesthesia providers, would provide a method to learn that is exciting, anatomically correct, inexpensive, and of no risk to the patient.

CHAPTER TWO: REVIEW OF LITERATURE

The literature describing epidural anesthesia currently includes traditional textbooks, articles and CD-ROMS. Reviews of VR systems and displays are also found in current literature. Reviews of books and articles relating to epidural anesthesia teaching are presented. The creations of 3-dimensional or virtually rendered anatomical models of the lumbar and epidural regions of the human body have been reported. An interactive CD-ROM that teaches regional anesthesia is also included. A book reviewed gives a detailed history of Virtual Reality. Several articles reviewed discuss points of view on the use of virtual reality in medicine, and include VR in surgical education, endoscopic surgery and VR in anesthesia. This literature will be discussed and summarized.

Regional Anesthesia--An Atlas of Anatomy and Techniques

In the book Regional Anesthesia--An Atlas of Anatomy and Techniques edited by Hahn et al. (1995) the reader is presented traditional information that has been well described in the past by using computer-generated graphics. The first chapter discusses pharmacology of local anesthetics. Several important features are present such as quick reference tables that provide information on local anesthetic doses, duration of block and toxicity of the anesthetics. These are presented in a colorful and easy-to-read format that makes quick access easy. Chapter two discusses equipment used for as well as information on nerve stimulators. There is additional information about local anesthetics and toxicity. The remainder of this atlas covers specific regional blocks. Each block is specifically discussed with procedures and complications identified. Also included are sections on specific blocks often performed by surgeons such as pudendal, digital and

dental blocks. It is surprising that several blocks were omitted from this book such as the sacral plexus block, the phrenic nerve block and thoracic and cervical epidural blocks though lumbar epidural techniques are described. The information is clear and concise however, the procedures are not written as a quick-reference to be read prior to a block.

The anatomical drawings are unique in this text and many computer-generated images are included. These images give the reader a new perspective because of their 3-D design. Although these images have been created from computer-generated data and not real human anatomical data, they simulate important structures well and show a new use for computer imagery not previously used in regional anesthesia textbooks. There are also radiographic and high-resolution color photographs used to depict the anatomical landmarks that relate to the block being described.

Although this regional anesthesia atlas describes procedures that have been described many times before, it incorporates new computer graphics to enhance the learning process for anesthesia students. This is an important beginning for incorporating new computer technology into the world of anesthesia and medicine.

Interactive Regional Anesthesia

Fernandez et al. (1995) have created an interactive CD-ROM that provides good general coverage of regional anesthesia. In order to use this CD-ROM the student must have access to a computer with minimum hardware requirements including an IBM PC-compatible computer, Microsoft windows 3.1,486-25SX MHz processor, double-speed CD-ROM drive, 8 megabytes RAM, sound card, and 16-bit color with a color monitor. The disc contains information about the history of regional anesthesia that is brief and

accurate, sections on physiology and pharmacology, epidural and spinal anesthesia, and sections on specific extremity blocks including the head and neck. This is a good example of what can be done with conventional information using computer technology. There are several hypertext references for charts and other features that quickly move the learner from section to section. In the section upper and lower extremity blocks, there are several anatomical graphics with peel-away sections removing layers of tissue. Simple mouse point-and-click movements control many of the functions. There is a section where a nerve stimulator can be placed over a nerve and a Quick-time movie will show the muscular response to stimulation of the nerve chosen. Some of the movie sequences can be slow even on higher-end computers. There are also graphics that have labels, which pop up when the mouse is pointed over certain anatomical structures. The section on spinal and epidural techniques covers the topic adequately, however the graphics and animations show limited positions for needle entry.

Overall this is a good endeavor, which allows the student to work at his own pace, and would allow a good review for an anesthetic provider. As computer technology advances, there can be several new ways to improve interactivity added to an instructional CD. In addition, databases such as the Visible Human ™ could be used instead of artist renderings. Specifically, a section in which the user positions the needle himself and attempts entry into the appropriate space could enhance interactivity. Simulators such as this have been created, but on much more powerful platforms and at much greater cost.

A Dual Technique for Identification of the Epidural Space

Jacob & Tierney (1997) describe the method of identifying the epidural space by using the loss-of-resistance technique coupled with acoustic amplification obtained through the epidural needle. As the epidural needle passes through the interspinous ligament and the ligamentum flavum and enters the epidural space, the sounds made by the needle can be amplified using simple equipment and provide a second indication of entry into the epidural space. This auditory cue can help augment the loss-of-resistance technique and possibly prevent accidental dural puncture. The authors suggest that this dual technique may be useful for difficult epidurals and may be useful as a teaching aid. One disadvantage may be that once trained, a practitioner may become dependent on sound, which would make the technique more difficult if proper auditory equipment was not available.

Segmentation of the Visible Human ™ for High Quality Volume Based Visualization

Schiemann et al. (1996) described segmentation of the Visible Human ™ dataset on high-end computers for the purpose of reconstructing three-dimensional models of these bodies. This document describes step by step procedures for the segmentation and reconstruction processes.

The author states that using volume visualization of medical images has become a standard tool used for many purposes such as craniofacial surgery but many fields still find difficulty in using these methods. Using volume visualization in the clinical arena is not realistic at this time based on the need for scanning, segmentation and reconstruction of images needed for each patient. Applications for teaching radiology and anatomy have

been created using CT or MRI data. This data need only be reconstructed once, however, these images suffer from a lack of realism and detail because of the medium used to obtain the data. This limitation can be overcome by using the high-resolution color photographs from the Visible Human ™ Project. Another comment made in the introduction indicates that although there are several browsers available, there is still a lack of three-dimensional applications. One of the reasons is that the formidable size of the data precludes the use of the data on many computer systems that cannot handle files of that size. Another reason is that current computer algorithms cannot accurately determine surface location or orientation.

The Visible Human ™ male cross-sections are described with a pixel resolution of 0.33 mm and slice distance of one mm. The CT and MRI data is also described. The cadaver was cut into four parts before being sectioned for photographs. This caused shift artifacts, which are visible as horizontal lines in the 3-D reconstructions. Another one of the difficulties in using this dataset is that each photographic image is of such a large size that the computer requires hundreds or thousands of megabytes of memory in order to store regions of the body. Schiemann and his co-workers reduced the resolution of these images by averaging 3 x 3 pixels to one pixel on every slice. This reduced a 440-megabyte volume to 49 megabytes. This made the procedure much simpler on high-end computers.

Three different approaches are described for 3-D visualization. First is the rendering of triangular surfaces, next is volume rendering by projection of the entire volume under different constraints, and last is volume-based rendering of surfaces which have been obtained from previous segmentation. Triangle surface rendering is the fastest

method if the number of triangles is kept low but the image loses detail during processing. It is felt that volume based surface rendering is the most advantageous for this project and although slower than triangle surface rendering, it can still be done on most high-end computers and can provide a high level of detail and realism. The disadvantage of slow speed will be overcome by future hardware. The authors feel that since most objects appear as ellipsoids in RGB (red-green-blue) space, classified regions would be described as ellipsoids instead of blocks shapes. A semi-automated procedure was used for segmentation, which provided great detail in resulting volume renderings. Ellipsoid-shaped areas were placed over areas of interest. These areas were then extracted based on their RGB color. Further mathematical morphology was used to remove attached structures. Several highly detailed regions such as the gyri of the brain still need to be segmented manually due to limitations in software algorithms. The third method of visualization was not discussed.

At the time of publication, these researchers have reconstructed several regions of the Visible Human ™. The head, upper abdomen and right shoulder have been completed. Although several organs can be reconstructed in a few minutes on a high-end machine, additional interaction on individual slices is recommended to ensure accuracy and improve detail. The authors conclude that their methods of visualization are superior to other approaches published at that time. Although their methods represents a new quality of anatomical imaging when used in state-of-the-art visualization systems, much work still needs to be done towards completing a 3-D anatomical atlas. It was not mentioned however, the software used to complete this project. It may have been created specifically for this project by the authors.

Virtual reality: Through the new looking glass

Pimentel, K.,& Teixeira, K. (1995) wrote an exhaustive history of computer graphics and Virtual Reality in their book Virtual reality: Through the new looking glass. It also discusses current trends in computers as well as future possibilities.

Background of Computer Graphics and Virtual Reality

As far back as history is written, man has been artistic, and has created things that fulfill these descriptions. Theater was used in the Roman era as a way to create an artificial reality. All that was required was an actor and the suspension of disbelief. Music was also used as a method of self-expression, and a way to transform oneself, perhaps taking one to another place. Paintings were and continue to be an artificial way to recreate reality or invent a new reality. In 1788, Robert Barker improved on painting to increase the sensations created by his paintings, and found a way to *immerse* a person in his vision. He painted a 360-degree view of the city of Edinburgh that was the first artificial panoramic view of the city. The observer could stand in the middle of the panorama and see nothing but the city. This helped suspend disbelief and immerse the observer into the experience. In another attempt to augment reality, the stereoscopic viewer was invented in 1833. This device had two separate eyepieces that simultaneously viewed two slightly offset photographs of the same scene. This gave the perception of depth to pictures that had previously been seen as one-dimensional. This device was bulky and finding pictures for it was difficult, but in 1844 the process of stereo photography and the device itself had been refined. This new device was the precursor to the popular Viewmaster that appeared in the 1940s.

Photographs became very popular but once again, inventors such as Thomas Edison felt the need to augment the reality of static pictures. Flat pictures could only tell a limited story, so Edison believed that moving images that could tell a complex story would be well accepted by the public. He invented the Kinetoscope that was based on a loop of film that showed a series of photographs to accompany his phonograph. From this technique, two brothers, Auguste and Louis Lumiere created the first motion picture and called it *cinematographe.* Now, this ability to synthesize reality was used to capture lives on film, and create new experiences. The public demanded more and the technology was rapidly developed, the results of which can be seen today as created by Hollywood filmmakers.

Television was invented in 1941, and had much of the same effect then as virtual reality has now, excitement and wonder. Television brought a virtual environment that had been created by artists, into the home, but it was initially cost prohibitive and of very poor quality. Soon the technology grew to include the capabilities of creating things only imagined before. The Sensorama was developed in 1960 by Morton Helig. It gave customers an experience like none they had ever had before. A freestanding machine was developed that included a motorcycle handlebar, a seat, a fan that could blow wind, stereo headphones and binocular-type viewing screen which could show stereoscopic images. The patron was seated on this "virtual motorcycle" and viewed a motorcycle ride through Brooklyn. The "rider" was able to hear the sounds of the city, feel the wind blowing through his hair, feel the seat vibrate and even experience smells as the motorcycle rode past a bakery. These stimuli were activated in synchronization with the movie. Helig, however, never received the financial backing he needed from Hollywood in order to

reduce cost to the customer, so this machine was hidden away. This type of full-sense virtual experience has never been duplicated.

"Virtual reality is about computer graphics in the theater of the mind." This definition is one of many that include technology as a factor. Virtual reality has also been defined as computer graphics used to form an illusion. Though computer graphics nearly define virtual reality today, its origin begins with the flight simulators of the 1950s.

Navy flight simulators during the 1950s were greatly improved by the use of cameras that moved over scale models of airports. The image was then projected onto a screen in front of the pilot. Further developments saw the use of three cameras, which projected images across a range of 180 degrees from the pilot's view. This greatly enhanced the realism of the simulation.

Computer Graphics

The first computers were developed in the 1940s. Many years later computer graphics were developed after the invention of minicomputers without tubes in the 1960s. Prior to this, the computers were so large that they occupied entire rooms. They were used for mathematical calculations, but were not *user friendly* and had to be controlled by a computer expert, or programmer. There were no significant computer graphics to speak of in these transistor-based computers, until Ivan Sutherland pioneered the use of a screen that could represent the computer's data. Prior to this only punch cards were used to communicate with the computer. In 1960, he developed a light pen that could draw graphics on the computer screen, which were then transformed into data. This was the earliest precursor to the multi-billion dollar Computer Aided Design (CAD) business of today. Sutherland has since been known as the "father of computer graphics". The

creation of these two-dimensional drawings was the first representation of three-dimensional information on a flat screen. Soon, General Electric Corporation built the first computer image-generation systems for the space industry. Sutherland's next development was the first computer-generated head mounted display (HMD). This device, dubbed the "sword of Damocles" due to its large mass of hardware mounted on the ceiling above the user's head, was attached to a helmet worn by the user, and the image was projected onto two small cathode ray tubes (CRT) in front of the user's eyes. The aerospace industry quickly adapted this technology for use in simulators for pilot training.

Early Virtual Reality

In the 1970s, Kreuger utilized the emerging graphics capabilities of computers to create a completely computer-generated 'artificial reality'. In his project called Videoplace, a camera was focused onto a person and a shadowed image of that person was created on the computer screen. The shadow followed and duplicated the movements of the person utilizing the program, or *user*. A *sprite* or small character was created on the screen in the form of a ball, in shadow form, and was named "Critter". Critter was able to climb the user's shadow and remain attached to the shadow as it moved about the outline. The user could move, and Critter would follow, even to the point of hanging from a finger. If the user "shook" critter off, he would fall to the bottom of the screen, then begin to climb again. This was the first truly interactive program created for a computer.

In the 1970s, Kreuger created a project called "Grope II" at the University of North Carolina. This program could display 3-dimensional molecular structures on the screen, and allowed manipulation of these structures by the user. By utilizing protein and

nucleic acid structures, the chemists were able to combine molecules using either *allowable* or *forbidden* docking sites between drugs and other structures. This allowed chemists and pharmacologists to create new chemicals and drugs without the risks encountered in a laboratory. This has since progressed to Grope III with several modifications, and is still currently used.

While working at NASA Ames, Dr. Michael McGreevy built the first *Virtual Workstation* with the help of Jim Humphries and others. The end result was a *Head Mounted Display (HMD)* for use with computers, instead of the standard television-like screen. The two thousand-dollar HMD was constructed from two very small Liquid Crystal Display (LCD) screens, similar to today's Sony Watchman. These were mounted into a helmet that the user wore with only a cable attached to the computer. This was originally used to display air-traffic information directly to the eyes of the controller, so he could have instant access to important information, but not have to look away from visual contacts. This was the basis for what is now called a *Heads-Up Display (HUD)* which is currently in use by fighter pilots. The HUD was adapted to provide the complete visual field of the user, and head-tracking devices were installed. The head tracking devices could identify the pitch, yaw and rotation of the user's head, and translate that information to the computer. As the device sensed that the user's head turned to the right, this would signal the computer's program to redraw the graphics from a new, mathematically calculated perspective, and redisplay them on the two small television screens in front of the user's eyes. This was the template used for the Virtual Reality technology used in today's most advanced games.

The Dataglove

Thomas Zimmerman developed the first movement-tracking glove in the late 1980s. The glove had sensors that were capable of detecting the amount of *bend* of the user's fingers, and transmit this data to the computer. It also had touch sensors on the fingertips to detect when an object was touched or *grabbed*. This glove was used to generate music from several invisible instruments, and was then dubbed, "the ultimate air guitar". VPL research developed a commercial version of Zimmerman's glove, and called it the "Dataglove". NASA saw the possibilities of this tool, and soon developed several *virtual environments* that could be interacted with using voice commands. Incorporated into the virtual environment was a source of 3-D sound, which added a quality of realism to the display. The Dataglove was also incorporated into the environment as a tool for manipulating 3-D objects that were virtually created and projected into the user's view. It was at this point that the user became totally immersed in the environment.

Modern Computing

The 1980s are when this advanced use of computer graphics and emerging technology was developed, and because of the rapid development of this technology, the age of the home computer era was born. The market was soon flooded by simple games such as Pong, and quickly followed by games on the Atari, Commodore and Apple brands of computers. It is ironic that these computers, though developed as game machines, became the early mainstays of home business equipment, while IBM computers originally developed for business programs, didn't find a way into the home until programmers began game development for IBM machines.

Interactive 3-D Graphics and Virtual Reality in Medicine

The science of Medicine had little use for the new science of computers until very recently. It was found that not only could computers store vast amounts of medical information, but they could actually be used to assist persons with disabilities encode and interpret Magnetic Resonance Imaging (MRI) scans (1980s) and Computerized Tomography (CT) scans (1970s), and assist with visualization during surgery (O'Brien & Ezquerra, 1996). Though computers cannot completely control the functions missing in those with disabilities, they can enhance those abilities, or replace them altogether. Computers can now help the consumer perform daily routines and duties that he may not be able to do otherwise. For those with the ability to use a hand, the Dataglove can detect hand gestures and translate them into commands which activate pre-programmed instructions such as dialing the phone, or operating a robotic piece of equipment. A program known as "Glove Talker" was created for those without the benefit of voice. Hand gestures are transmitted to a voice system, which allows the user to communicate. These systems work well after some time is invested in "training" the computer to recognize the hand signals. A universal system was developed that recognizes sign language, and is called SLARTI. Standard signing is used, recognized, and the computer through speakers pronounces words. These voices sounded robotic and artificial when first developed, but through the use of digital recording or sampling techniques, the voices sound more natural and human.

Virtual Reality in Anesthesia

One very pertinent article was written by D. E. R. Burt (1995) entitled *Virtual Reality in Anesthesia.* The review article covers the history of VR, components required

in a VR system along with other hardware that has been developed, applications of VR in medicine and anesthesia, anesthesia simulators, and future developments in VR.

The article starts with a brief description of virtual reality as having "captured the public imagination". Aside from the uses of VR in entertainment, it is currently being used commercially in Japan to train workers for nuclear weapon repair and disassembly. The author notes that "the decommissioning of nuclear weapons has been made considerably less hazardous by the use of virtual reality techniques." Workers are able to train on disassembly of weapons, and can react to critical incidents as they arise without any risk. The medical field has begun to use and develop VR projects of its own, and has spawned several conferences related to medicine, the most publicized known as "Virtual reality in surgery and medicine" (p. 472). Burt states that there may be unrealistic expectations for VR in medicine based on limitations of the computer hardware and programs, similar to those of the early 1970s, when artificial intelligence was considered a new breakthrough. The difficulties encountered in medicine include problems translating the clinical diagnostic process into knowledge of engineering terms, a failure of software programmers to create medically useful software, and the deficiency of hardware design.

Virtual reality is defined in one way by the author as "simply a more imaginative way of providing a human-computer interface than the standard keyboard, mouse and screen system with which we are familiar" (p. 472), though he states that a single definition is difficult to assimilate. The user becomes an interactive part of the virtual world in which objects created by the computer are manipulated. These objects can be images of the real world recreated, or can be artificially constructed from imaginary

sources.

The history of VR starts with the defense and aerospace departments and the use of flight simulators. Originally, cameras were hung over scale models of airports, and pilots could see the camera view through a "cockpit window." Ivan Sutherland pioneered computer graphics, which were then quickly adopted by the aerospace and defense industries. Graphics that represented three-dimensional objects on a two dimensional screen were soon developed into computer-generated scenes and used in the simulators. At the same time, Sutherland was developing the first Head Mounted display that used small cathode ray tubes (CRTs) mounted inside a helmet. Visual coupling, the process of updating graphics to continually display appropriate orientation of scenery when the head is moved, was developed soon after. These developments have evolved into the relatively low-cost HMDs of today's virtual reality games and pilot simulators.

An important point the author makes is that many valuable principles were developed during the creation of VR. Update rate, or the rate at which an image should be refreshed were established to help simulate realism. The amount of graphic detail became important, as did perspective and techniques for orientation of the objects in reference to the user.

Burt next discusses how virtual reality is created by defining several terms. Immersion, interactivity and feedback were mentioned as they were earlier in this paper. There are also lengthy discussions on software, hardware and equipment that has been developed for use in virtual applications.

Next, the current initiatives in medicine and anesthesia are mentioned. "Several centers are currently developing laparoscopic training simulators which aim to provide

haptic feedback during instrument manipulation of virtual tissues and organs." This, though true at the time of his writing, is now a reality since there are virtual laparoscopic trainers available for purchase. These simulators provide feedback as resistance during instrumentation of virtual tissues. This may allow surgeons who rarely perform certain procedures to train ahead of time without the cost of time in the operating room, or risk to a patient (p. 477.) Burt states that the time spent on specialist training and reduced working hours of trainees will reduce the exposure to clinical material during training, but that it is necessary to keep standards high, and keep specialists well trained in a cost effective manner. Virtual reality in a simulator setting is one way of doing this.

Burt states that another area of research has been that of anesthesia specific simulators. These vary from completely virtual environments that contain virtual patient and anesthesia machine, to computer-controlled mannequins that respond to intervention through computer constructed "models" that represent body systems such as the cardiovascular and respiratory systems. The complete virtual environments are still under development and awaiting advancement in haptic feedback, while the mannequin type of simulator is currently in use, on display, and research on its effectiveness is being done. The advantage to the latter type of simulator is that it can be used to teach and test critical thinking and skills in emergent situations without putting a patient at risk of accidental injury.

Most pertinent to the project being created for this thesis, is the section on procedure training. Neurosurgical and local anesthetic training uses are discussed. Image-guided neurosurgery uses virtual techniques to assist the surgeon. A three dimensional image of the head is reconstructed, or rendered from two-dimensional CT or MRI scans.

The image then registers the location of a mechanical pointer, which is attached to the patient's head. The location of the pointer is shown on the screen so the surgeons can decide on exact positioning. This technique is expected to replace the stereotactic frame-based procedures used now (p. 479). It could potentially be used to train anesthesia providers how to perform a local block of the orbit.

"Teaching practical procedures such as central venous cannulation, peripheral nerve block, extradural and spinal blocks will be greatly facilitated by the use of computer graphics which may be made to display the anatomical relations to the end of the device as the procedure continues"(p. 479). This statement is the foundation on which this thesis is based. There are several regional training devices based in VR that are commercially available such as interactive CD-ROMS and an epidural needle placement simulator from the University of Colorado. Technology still seems to lag behind the expectations of the medical community. Burt states that the type of graphics required are only available on the more expensive Silicone Graphics type work stations, though a new wave of video cards for personal computers is expected (p. 475). There are several cards available for the PC, but at great expense and with only marginal performance. Advances in display screen technology are being made as well. The author expects that these developments may be well expected within the next ten years, and many already have arrived.

In one, perhaps two year's time, Burt's article has been outdated in that many of the technologies thought to be difficult to achieve have come to fruition. It seems to be very complete in its historical content, concept of VR and its equipment list. Review

articles, in order to remain as current as the technology, apparently should be rewritten yearly.

Virtual Reality in Medicine

Kaltenborn & Rienhoff (1993) wrote a review called "Virtual reality in medicine." It encompasses the history of virtual reality and several definitions, similar to those described earlier in this paper. The authors describe three attributes that are necessary for the user to experience true virtual reality. The first requirement is that a three dimensional representation of a VR model be used. It can include auditory, tactile, or haptic feedback devices, as well as head-mounted displays to make the virtual world more realistic. The second requirement is that the interactivity of the user be in real-time. The response time for feedback should be in a time fashion that simulates reality, thereby adding to the experience. The third characteristic is that there be a "human-oriented interface which allows natural human communication such as gestures and language." True VR offers special human interactivity through the use of Datagloves, rather than keyboard and mouse. A considerably in-depth discussion of the technical aspects of virtual reality was discussed along with the problems of the available systems. There is a vast array of systems available for creating and producing virtual environments, and several devices such as the Dataglove and HMDs that help add reality to the virtual experience, but the creation of realistic environments is limited by the technology. Expectations seem to be higher than the equipment can provide. In describing necessary equipment, Kaltenborn differentiates between Real Environment Sensing (RES), Virtual Environment Display (VED), and Virtual Environment Control (VEC).

RES systems provide real-world information to the computer for processing. Body gestures, positions and even speech inputs are used to mediate the objects of the virtual world. The Dataglove is the most significant of these devices, closely followed by head-tracking devices or head-mounted displays (HMD). Speech recognition and eye-tracking devices are still in their infancy and need a lot of technical refinement.

The Virtual Environment Display is the part of the system that delivers information to the user through visual, auditory, or tactile feedback. The requirements for a computer to draw and redraw three dimensional graphics are quite complex, and current display systems redraw at a rate that is slow enough for detection by the human eye, thereby decreasing the realism of the visual cue. This is known as the *refresh rate*. As technology improves, the refresh rate will become faster than the eye can detect, and improve the experience. Future applications to add to visual realism include a combination of holographic and laser technology. There are also proposals to produce the image directly onto the retina using laser technology. As discussed earlier, NASA has developed 3-D sound technology, which enables the user to identify different spatial origins of sound during the virtual experience. There is current work on haptic, tactile, audio and even thermal feedback devices to enhance realism in the virtual environment.

The Virtual Environment Control (VEC) system is the most technical of the systems. It is responsible for receiving the input data, controlling both the feedback and the objects in the virtual environment, based on rules provided for that object by the rules for that environment. Such examples include doors opening on only one axis, balls bouncing according to the laws of gravity, or in a slightly modified environment, the extravasation of blood when a capillary is cut. The VEC must compute all this data in a

very short period of time, and if the system can't meet the demands placed on it, the virtual experience will be less realistic. Humans require delays between the user's input and environmental responses to be 10 milliseconds (ms) or less (p. 409), but current systems can only provide a speed of 60-70 ms response time. This causes perceptual delays, which can inhibit realism. A delay of 300 ms can even cause motion sickness in some people. This area requires improvement as well.

Several applications of VR in medicine were discussed in this review. Persons with disabilities now have available, many systems and devices that help normalize their lives. The company Greenleaf Medical Systems has three projects that involve helping the handicapped. The Movement Analysis System (MAS) uses a Dataglove to detect hand and wrist movements, then conducts computer-supported movement analysis for the purpose of assessing the therapeutic effects of rehabilitation therapy. Through this analysis, improvements in care can be achieved. Another project is the Gesture Control System (GCS). This system allows those with limited movement to command the computer to initiate any of several pre-programmed instructions, such as dialing a phone. This review also mentions the Glove Talker, and SLARTI recognition systems as were discussed earlier. In addition, Biomuse is a program that allows total control of the computer through eye, muscle and brain signals. These programs are not intended to provide a complete VR environment, but are aimed at providing disabled people with "a human-centered interface for carrying out various tasks using robots or computers" (p. 411).

In the surgical arena, there are several projects under construction. The use of image processing during Minimally Invasive Surgery (MIS) is still two dimensional,

though three dimensional image systems, stereographic or holographic are in development and show a tremendous amount of promise for the future. Three-dimensional ultrasound is capable of providing intraoperative orientation and morphology of tissue. Current use involves three dimensional ultrasound images to help determine fetal abnormalities.

Kaltenborn & Rienhoff cite CT and MRI images as being a very important part of the pre-operative planning period (p. 411). CT and MRI images have been used to control robotic systems, and perform brain resections and biopsies. The University of North Carolina at Chapel Hill is involved with three projects involving the use of CT, MRI and ultrasound images. The first, called "Project X-ray Vision" is intended to superimpose these images on a see-through head-mounted display (HMD). The surgeon will be able to simultaneously see the patient's anatomy while visualizing the computer-reconstructed images on his HMD. Another project titled "See-through Ultrasound" involves two-dimensional images that are computed, visualized and composed with video images, and then projected into the surgeon's HMD. Future advances in technology would allow the use of three-dimensional imagery. The third project entitled " Radiation Treatment Planning" was designed to assist in the irradiation of neoplasms. The surgeon wears a HMD that supplies the patient's anatomical data computed from CT scans. At the same time, a beam that represents the radiation is projected onto the display. This allows the surgeon to aim and focus the beam onto the tumor, and avoid most healthy tissue. VR applications for surgical simulation were mentioned, as future developments not currently in use, however, there are several surgical simulations available via the World Wide Web and the Internet.

The conclusions drawn from this paper identified VR as a novelty, with limited uses in the medical arena. The high costs of equipment and programming prove to be prohibitive to many researchers. Also, the technology was very immature at that time, but great strides have since been made. The authors state that medical uses outside of research will take 10 years or more before the technology will be used on a regular basis. This has proven false, since these technologies are being utilized at present, only a few years after their review. Assistance for the disabled was discussed as the "most promising fields of application" (p. 414) of VR technology. Though there have been many recent advances in this field, Other areas in the field of medicine are rapidly expanding. Our demands for VR interaction still far exceed the abilities of the equipment, but the development of advanced technology is gaining momentum at a rate faster than that of our imaginations.

Another example of the expansion of VR is the Responsive Workbench.

The Responsive Workbench

Frohlich et al. (1995) discussed the creation, uses and future applications of their "Responsive Workbench". The purposes for creating the responsive workbench are stated as education, a cardiology tutorial and surgery planning.

The desktop computer system has been enhanced over the last twenty years by devices such as the mouse, a windows-type environment, and multimedia extensions. This improved the way humans interacted with their computers. With the development of immersive environments, the user can now walk through a three-dimensional environment, and with the use of devices such as HMDs, body-tracking suits and force-

feedback exoskeletons, they can have the ultimate in artificial realism. The problem with many of these devices is that they are obtrusive, and costly. Another method of interfacing humans and computers comes in the form of responsive multimedia environments. These focus the user's attention and utilize many of the senses, but remain non-immersive. The authors created an alternative interface as a new way to interact with a virtual environment. It is named the responsive workbench and it is based on the principle that many scientists, physicians, engineers and the like work in a workbench type of environment. With this in mind, a table-based computer projection screen was created. A large video projector, a glass-top table and a large mirror were assembled into a system that projects the image from the computer onto the etched glass on the tabletop. The computer generates alternatively displayed images for the left and right eyes, and the images are then viewed through special shutter glasses which allow the user to see the image as a three dimensional object. All of the visual objects and tools are located on the workbench, or the visual field of the tabletop. The stereoscopic images are projected onto the workbench where they can be manipulated and studied. Speech, motion and gesture recognition systems can also be incorporated into the program, depending on the application. Several observers can view the objects at the same time through their own pair of shutter glasses. Head tracking devices are incorporated into the glasses so the image is projected at the appropriate orientation for each observer. Frohlich and the other researchers felt that the hand was the most natural input device for this type of interface, so a Dataglove was incorporated into the system. These gloves are equipped with gesture and collision detection systems that transmit data about object manipulation. Natural language was also incorporated into their system, so that commands such as "zoom in" or

"transparent" could be recognized. This system consists of a Silicone Graphics Onyx system, a high-end system capable of rendering and redrawing images fast enough that they are perceived as being touched, rotated or moved in "real-time".

The scenario chosen is based on a real-size model of a patient. The software programmers have created skin, which can be solid or transparent, bones, and some organs. Once visualized through transparent skin, the bone or other organs can be "picked up", rotated and zoomed-in on for further evaluation. They can be replaced by hand or spoken words. One of the advantages over the plastic skeleton model used by many medical students is that all the features of skin, bone and organ are seen in relation and proportion to each other, and can be stripped away from each other as desired. Two features that have been constructed by the authors include the beating heart and blood flow through the transparent heart. With this heart, practice with ultrasonography can be available to the physician. The clinician can sweep and rotate a transducer to obtain ultrasound images of the heart while it is being seen virtually. The images of skin and bone were created virtually using simulated data, but the heart was reconstructed using empirical data, thereby allowing the learner to visualize the workings of a real vs. artificial heart.

The writer identifies several future applications and extensions for the responsive workbench. Real human data from MRI and CT scans could be rendered into three-dimensional objects. The problem with this technique is that soft tissue and blood vessels can't be reconstructed, so a program that creates them is being written. High-resolution data from confocal microscopy of cells could be incorporated into the patient allowing much more detail as the user zooms in on a certain object. Incorporating stereoscopic

video images into the system could simulate endoscopy. There is even the potential for including laser surgery of the eye. In addition to these things presented by the author, there is great potential for several things of importance to nursing and anesthesia. Phlebotomy skills could be taught or enhanced through the use of a haptic needle, as could a spinal or epidural puncture. Other regional techniques could be taught if a nervous system was incorporated into the patient. Laryngoscopy could also be visualized with the aid of this virtual environment if stereoscopic video was included.

It is clear to see that the idea of creating and using a virtual human has been considered for many years but because the technology of computers lags behind the ideas of the mind, these concepts have not been created as we wish to see them. Because of the recent availability of high-technology computers and the Visible Human ™ dataset, the advent of a virtual reality-based learning system is here. We need to expand our imaginations to use these tools effectively and be creative in their use for higher learning.

CHAPTER THREE: FRAMEWORK OF STUDY

Theoretical Framework

From their humble beginnings, computers have been used to teach complicated tasks such as flight training (Pimentel & Teixeira, 1995), endoscopy and surgical training (Weghorst, 1994). Virtual reality models allow complicated three-dimensionally based tasks to be taught in a much more comprehensive manner (Satava, 1994). Anatomy has been taught from flat plates in books, but has been enhanced by three dimensional imagery provided in a virtual environment created by sophisticated computers (Dunkley, 1994). There are anesthesia-related simulators that allow providers to practice such procedures as phlebotomy, visualization of the trachea, and epidural needle placement (McDonald, 1995). These newly designed virtual reality simulators help improve comprehension of performing this procedure before attempting it on live patients. The new technology of computers provide new capabilities for providing expansion of perception, creative construction and unique social interactivity (Bricken, 1991).

The use of computer imagery and virtual reality encompass three important areas of educational theory: experiential education, constructivism and social learning. Virtual Reality graphics and virtual worlds create an atmosphere where the participants can be involved in many different learning experiences. The quality of immersion into a VR environment provides an experience that is fundamental to the learning process (Papert, 1980). Participation in a virtual experience involves "purposeful movement that coordinates the cognitive, the psychomotor, and the affective domains" [Harrow, 1972] which allows involvement of the entire body of the participant.

Encouraging students to construct their own knowledge has been demonstrated to be effective in the learning process (Spiro & Jehng, 1990). Anatomical data taken from its native form is transformed into digital data and then into visual data. This allows the participant to create, manipulate and edit any form of the digital information. By creating or recreating digital objects, images or situations, the user can participate in active problem solving. Bransford et al. (1990) states "In many instructional settings, students acquire only facts rather than acquire tools for problem solving. They often have not experienced the kinds of problems that make information relevant and useful, so they do not understand the value of this information."

"Human learning presupposes a specific social nature and social process" (Vygotsky, 1978). Digitized anatomical information can be shared between individual computers, or networked for interactive learning and collaborative efforts between users. The ability to use virtual information or virtual worlds to share ideas and points-of-view may intensify the social learning experience (Brown et al., 1988). Allowing teachers and students to use computers in a cooperative effort tends to make the learners more productive (Belkin, 1977). Hence, the basis of this proposal includes the manipulation of anatomical data, its transformation into digital data, and finally, its reconstruction into 3-D manipulatable images.

Methodology

The Uniformed Services University of the Health Sciences has licensed the Visible Human ™ Dataset for use in this and other future projects (appendix B). Because of improved resolution and reproduced fidelity of 3-D reconstructions from other projects, the VHF dataset was chosen for this project's reconstructions.

The first images were obtained through the WWW using a browser known as Netscape. The computer used to download the images is an IBM PC-compatible computer with a Pentium 200 MHz MMX processor, 32 megabytes of Random Access Memory (RAM), a 3-D graphics accelerator video card with 4 megabytes of video memory, a 33.6-baud modem, a 2.1-gigabyte hard drive and a 17-inch SVGA monitor. The sagittal and coronal images (figs. 1-6) were found on the WWW at various sites that displayed information about their own VH projects. The coronal and sagittal views of the VHM and VHF were reconstructed from the original transverse cross-sections using many different computer software programs. The software was created for the specific project by the researchers in most cases.

Original transverse cross-sections of the VHF were downloaded from the NIH's Internet File Transfer Protocol (FTP) using the same PC as above. Directions for downloading to a Macintosh computer were available (appendix E), however the download procedures for the PC were developed during this project. First, the images were downloaded in JPG format, an image-compression standard that provides a large amount of image-size compression in order to save hard-disk space, but sacrifices image quality. Three hundred-fifty images were obtained from both the VHM and VHF datasets

and evaluated to help identify which image sections and NIH image numbers would be used in the final display. After the proper images were identified, the full-size 24-bit color sections were downloaded. Twenty-five photographs from the VHM and the same from the VHF were downloaded. Each image is 7.5 megabytes in size, and took 30-40 minutes each to download using a 33.6-baud modem and a standard phone line. A megabyte is defined as one million bytes, or typewriter characters. One double-spaced typewritten page is approximately 1.9 kilobytes, or 1900 bytes. A Computer image of this size, 7,500,000 bytes, is equivalent to 3947 pages of text; a stack of about 10 inches thick, or laid end-to-end, a distance of approximately 2/3 of a mile.

Each image was uncompressed to approximately 8 megabytes. This made manipulation of these images a more difficult task. After the images were restored to full size, they were viewed using a shareware program named PaintShop Pro (PSP). An example of the 24-bit full-color image is shown in figure 7, at 1/4 of its actual size. Each image was scrutinized for details that would be important for an anesthesia student to know. Using PSP, the images were cropped to an appropriate size and annotated with identifying labels. Figures 8-17 have an additional image in the upper right-hand corner that identifies the location of the transverse section. These smaller "icons" were created with PSP using the coronal sections obtained from the University of Colorado online, (http://www.vis.colostate.edu).These coronal sections are included as figures 3 and 4.

The hardware needed for the reconstruction of Visible Human ™ Data has been provided by the University. It consists of a high-end Sun Sparc II computer running the UNIX operating system and has 3D video capabilities, 128 Megs of RAM, a 4 gigabyte hard-drive, a T-1 line connection to the Internet, and a photographic-quality color printer.

While the computer workstation was being obtained and secured for this project, the process for licensing the software was completed. USUHS now licenses software called Analyze ™, produced by the Mayo Clinic, for a one-year period (appendix A). The software package was designed specifically for use on UNIX-based computer systems so it installed on our system with little problem (appendix C). Images were downloaded from the NIH FTP site using USUHS's T-1 Internet connection. This allowed image download times that took only 30 seconds for each image as opposed to 30 minutes each over a standard telephone line. A total of 150 images were obtained from the VHF. Each image had to be uncompressed from its native compressed format (raw.Z) to its uncompressed size. Using the UNIX command "Uncompress *. raw.Z" allowed all the files to be restored in succession using this single command. Each image was then converted to an Analyze ™ specific file format by renaming them one at a time. No batch conversion of names was available.

A header that contains image attribute information had to be created for each image individually. One header was created that included the correct pixel size and dimensions, but the color format (24-bit RGB) had to be changed to 8-bit grayscale. This was done because Analyze ™ can't volume-render 24-bit color images directly. The header was then named with the same name as the first image. This header was copied 150 times and each was renamed to match its target filename. Each image now had two files, the image (.img) file and the header (.hdr) file.

Having been re-named and a header created for each image, all of the images were converted into a single volume file with a single header identifying its attributes. This process was handled simply in the Analyze ™ program. The volume image could now be

viewed using the "volume render" program in Analyze ™, which compiled all of the transverse sections into a stacked image. Although 150 images were used, each set of three equaled one mm in height, thus a total of 150 images only amounted to 50 mm of reconstructed body. The image height data located in the header was changed to 1 rather than 0.33 in order to gain more height in the viewed image. This however, stretched the reconstructed images somewhat. It did allow us to visualize the structures of interest better.

The images that were chosen to be reconstructed for this project were found in the region of the Lumber 3-4 interspace of the VHF. The reconstructed slices were still surrounded by the blue gelatin that surrounded the specimen while frozen (fig. 7). Using a thresholding program in Analyze ™ the blue portion of the image was subtracted and allowed the volume-rendered image to be viewed alone.

Two methods of identifying and separating specific objects in the reconstructed file were used. Some sections such as the lower back muscles were identified using the first method, the "autotrace" function of the program. Once a color intensity threshold range was identified that defined the muscles of interest, the program outlined the selected portion. After careful correction of the threshold parameters, the image was outlined properly and saved. This was done on several individual slices, but this proved time-consuming. The autotrace function was then applied to the volume file. Although this worked well with some of the slices, there were many slices that were not traced completely or properly. These image slices had to be traced by hand and saved. This again proved to be time-consuming but allowed the objects to be specified.

The second method of identifying specific objects in the volume file was based on eroding and rebuilding the image. Once the volume-rendered image was in memory, the erosion program removed a certain percentage of the image surface until a region of interest (ROI) was seen through the eroded image. A "seed point" was then placed on the ROI from which the specific region could be regrown. The erosion process was performed several times until the ROI was no longer connected to any other structures. From this point, the regrowing of the seeded ROI could be accomplished without re-connecting it to any other structures. This method didn't work well with the vertebrae because some of the original transverse sections sliced the vertebrae at a slight angle.

The regions of interest (ROIs) for this project include the lower back muscles, the vertebrae, the spinal column and the spinal cord. The dura mater is not well visualized on these images so reconstruction of the dura would be impossible. The spinal cord is located from the L2-3 interspace and higher, and was volume-rendered, but is difficult so see in detail because of its small size.

Figure 18 shows the reconstructed lumbar region with all of the ROIs visible. The image on the left shows the view from the skin whereas the image on the right shows that the skin, ligaments and spinous processes have been removed or "clipped" from the volume to the level of the spinal column. The white substance in the spinal canal is the epidural fat contained within the epidural space. When a few more slices are removed from the face of this image, the individual fibers of the cauda equina are visible.

CHAPTER FOUR: DATA COLLECTION

Computer Image Reconstructions

Although the data sets were collected as cross sections, complete reconstructions of skin, bone, muscle and organs have been completed. Figures 1 and 2 are reconstructions of the integument. Note that the male's tattoo was captured and reproduced with impressive fidelity (fig. 1). The entire male and female data sets are available to licensed institutions and qualified individuals for use in programming and educational endeavors.

Anatomic Plates

The Uniformed Services University of the Health Sciences (USUHS) licensed the Visible Human ™ dataset for use on this project. Cross-sectional data was obtained through an FTP Internet connection and analyzed for content pertaining to the epidural region (Table 1). The Visible Human ™ Male (VHM) and Visible Human ™ Female (VHF) datasets differ in several respects. The terminal part of the spinal cord known as the conus medullaris is found in different locations. It lies near the L2 to L3 interspace in the VHM, but it lies closer to the L1 to L2 interspace in the VHF. This was evident on review of the sagittal sections of the male specimen however, a sagittal reconstruction of the female was not available so the location of the conus was determined by examination of the transverse cross-sections and compared to those of the male. Figure 5 shows the male sagittal section, but does not show the full length of the spinal cord. After reviewing several sagittal plates, the conus medullaris was found and is shown in figure 5a. An important finding was made on the sagittal section of the male. Noted was the caudad

transposition of the brainstem and cerebellum through the foramen magnum, known as tentorial herniation (fig. 6). Also noted is the space present in the occipital region of the brain. These findings may have been caused by increased intracranial pressure at the time of death or perfusion, therefore one should be cautious about noting the precise locations of brain and cord structures due to tentorial herniation and possible movement of the spinal cord. Examination of the cross-sections showed that the mid-lumbar enlargement in the male specimen is found at approximately the 11th thoracic vertebral level, but is found at approximately the 12th thoracic vertebral level in the female. This may be a normal anatomical variation between male and female, or it could be due to repositioning of the cord during or after the death of the donor. Figure 14 shows the epidural space at the level of L-3 to L-4 in the male subject, and figure 16 for the female. These were enlarged to show the detail in the spinal canal and surrounding regions (Figs. 15,16). Several important plates pertaining to the epidural region were labeled with specific anatomic landmarks that would be important for a student anesthetist to learn and be able to identify. Figures 8-17 display different cross-sections throughout the body. Important landmarks and anatomical structures have been labeled.

CHAPTER FIVE: DISCUSSION

Discussion

Epidural anesthetics are the most commonly administered regional anesthetics used in this country. Anesthesia educators are continually looking for different and better methods of teaching regional anesthesia without risk to the patient but in a cost-effective manner. We have found that a new model of human anatomy can be created on computers to enhance the teaching of epidural anesthesia, however there are a few obstacles that must be overcome.

The only available real human data set at this time is from the Visible Human ™ project. It can be licensed by educational institutions for a moderate yearly fee. Collection of CT, MRI, and section data is easy, but time-consuming to acquire through the Internet FTP connection using a standard phone line and modem. Data collection times can be decreased significantly by using a large bandwidth connection such as an ISDN or T-1 line. Most universities are equipped with this type of Internet connection. Once collected, the data can be cumbersome and difficult to manipulate on smaller personal PC's. Many university settings have upgraded to high-end Pentium PCs and Macintosh systems with can handle these images fairly well. The more graphics-capable Sun or Silicone Graphics systems can handle these images much faster, and are available in some university settings.

Several software packages are available that can volume-render 3-D objects from various sources (Appendix D), but finding one that was compatible with a UNIX-based system that could handle CT, MRI and hi-resolution RGB images was difficult initially.

The Analyze ™ program was the only software that was found that fulfilled these requirements but the cost prohibitive since this is an individual research project and not a university-wide project. The university was able to license the use of the program for one year at a reasonable cost and it was installed in one of the university's computers. Installation and debugging of the Analyze ™ program took several weeks but once the technicalities were understood the creation of 3-D volume rendered objects from the Visible Human ™ dataset went relatively smoothly. Several high-resolution 24-bit color plates identifying important anatomical details were created easily on a high-end home PC using the Visible Human ™ dataset. Three-dimensional reconstruction of the lumbar region back muscles, spinal canal and spinal cord were completed using the Analyze ™ program (fig. 18). The Analyze ™ program has a multiple object mode that allows the user to view several objects simultaneously. These objects can be manipulated and separated from each other to enhance the view of all sides of the object. An annotation mode is also available so the images can be labeled. In addition, there is a movie mode so that rotations or movements of objects can be saved, viewed and distributed to others. These data can now be used as an adjunct for teaching epidural anesthesia using a UNIX-based system, or converted for use on PCs or Macintosh systems.

There are an incredible number of potential uses for this type of data, most involved with some teaching method. There are currently several reconstructions of the Visible Human ™ male and female datasets available now on the WorldWide Web. Some of these include the NPAC Visible Human ™ Viewer, located through the WWW at (http://www.npac.syr.edu/projects/vishuman/VisibleHuman.html), the Visible Human ™ Male Browser (http://www.uchsc.edu/sm/chs/browser_m.html), and Marching through

the Visible Woman (http://www.crd.ge.com/cgi-bin/vw.pl). There are also CD-ROMs that incorporate similar data into anatomical teaching multimedia presentations (Digital Humans) and even interactive displays on the World-Wide Web such as the Dissectable Human site (http://www.eai.com/www/interactive/dhuman/dhuman_cdrom.html) and High Techsplanation's Medical Virtual Reality site (http://www.ht.com/htweb/Test.htm).

Data that was reconstructed for this project could easily be incorporated into any of these educational titles or into the totally volume rendered Visible Human ™ male and female projects sponsored by the University of Colorado, the National Institutes of Health and the Mayo Clinic. In addition, this data could be copied onto a CD-ROM specifically targeting epidural anesthesia.

Other possibilities exist as well. Results from this project can be displayed on a WorldWide Web page sponsored by the USUHS's Graduate School of Nursing to show the use of new technology in anesthesia education. Through patience and programming the dataset could be made interactive over the web as well. The Naval Research Laboratory has a near-complete virtual human that is displayed on their Interactive Workbench. The data that exists there now is artificial, meaning created by programmers, but it could be replaced with the 3-D structures created during this project and future projects with the Visible Human ™ dataset.

Reconstruction of the Visible Human ™ male and female is just the beginning of a new technology. Now that the entire human beings (VHM, VHF) have been reconstructed from CTs, MRIs and frozen sections of cadavers, computer technology has advanced far enough to allow 3-D visualization of live patients' anatomy through 3-D MRI imaging. These images have been used to guide several surgical subspecialty

procedures such as neurosurgery, laparoscopic procedures and orthopedic surgeries. Medical industry is designing a way to superimpose 3-D images directly onto the patient. It will soon be possible to see the location of a tumor or injury *in* a patient before ever lifting a scalpel.

Conclusions

In the planning phases of this project and during the acquisition of equipment, the idea of using the Visible Human ™ dataset to recreate 3-D anatomy simply and inexpensively seemed difficult if not impossible. Costs were nearly prohibitive and software was cumbersome and not very user-friendly. Over the period of the last year, computer technological advances have been phenomenal and software that is both affordable and usable has become available. A technologically advanced, user-friendly and inexpensive method of teaching the anatomy of the epidural region or the procedure for an epidural block can now be created at the university level.

There are several things that need to be in place prior to starting a project such as this. First and foremost is securing licenses and obtaining permission to use the Visible Human ™ dataset, and Analyze ™ or other software. A high-end 3-D graphics-capable computer is needed to reconstruct, display, label and manipulate the slices of the Visible Human ™ dataset. This computer needs a minimum of 64 megabytes of RAM (128 Megs or more is preferable) and several gigabytes of hard-drive storage space. Three gigabytes of storage were used, but it was found that more space was needed after the reconstructions were completed. Technical support is essential both for the computer system and the Analyze ™ program. Being unfamiliar with the Sun computer and the

UNIX operating system. Several hours were spent with the technical crew solving computer-related problems. Although the manuals that were supplied with the software were used and we trained using the tutorials provided, many hours of software support were required from the software technicians at the Mayo Clinic and from an Analyze ™ user at NIH. Once the monumental task of learning the system and software was completed, the project became a bit simpler.

Once the computer and software problems have been solved, all that is needed is someone with enough computer skill to push a mouse, enough vision to see the future and enough fortitude to overcome the obstacles. Imagine each new student of anesthesia being issued his or her new textbooks and a CD containing his or her own virtually rendered human being. The only thing missing will be the smell of formaldehyde.

References

Bankert, M. (1993). Watchful Care: A History of America's Nurse Anesthetists. Continuum; New York.

Barash, P.G., Cullen, B.F., Stoelting, R.K. (1992). Clinical Anesthesia. Lippincott; Philadelphia.

Belkin, G.S., & Gray, J.L. (1977). Educational Psychology. Wm. C. Brown, Dubuque, IA.

Bier, A. (1899). Experiments regarding the cocainization of the spinal cord. Zeitschr Chir(51), 361-369.

Bransford, J.D., Sherwood, R.D., Hasselbring, T.S., Kinzer, C.K., & Williams, S. (1990). Anchored Instruction: Why we need it and how technology can help. Cognition, Education and Multimedia: Exploring Ideas in High Technology. Lawrence Erlbaum Associates, Hillsdale, NJ.

Bricken, M. (1991). Virtual Reality Learning Environments: Potentials and Challenges. Computer Graphics Magazine, 25(3).

Brown, D.L. (1996). Regional anesthesia and analgesia.. W.B. Saunders Company; USA.

Brown, J.S., Collins, A., & Duguid, P. (1988). Situated Cognition and the Culture of Learning. Educational Researcher 18(1), 32-42.

Burt, D. E. (1995). Virtual reality in anesthesia. British Journal of Anaesthesia 75(4), 472-480.

Dumay, A. C., Jense, G. J. (1995). Endoscopic surgery simulation in a virtual environment. . Computers in Biology and Medicine 25(2), 139-148.

Duncum, B. M. (1947). The development of inhalation anaesthesia. Oxford University Press: London.

Dunkley, P. (1994). Virtual reality in medical training. The Lancet 343, 1218.

Educational Affairs Committee, American Association of Clinical Anatomists (1996). A clinical anatomy curriculum for the medical student of the 21st century: Gross anatomy. Clinical Anatomy 9(2), 71-99.

Fernandez, O., Galindo, A. & Galindo, P. (1995). Interactive Regional Anesthesia. Churchill Livingstone; New York.

Frohlich, B., Grunst, G., Kruger, W., Wesche, G. (1995). The responsive workbench: A virtual working environment for physicians. . Computers in Biology and Medicine 25(2), 301-308.

Hahn, M.B., McQuillan, P.M. & Sheplock, G.J. Eds. (1995). Regional Anesthesia--An Atlas of Anatomy and Techniques. Mosby; St. Louis.

Harrow, A. (1972). A Taxonomy of the Psychomotor Domain. David McKay, New York.

High Techsplanations Inc. WWW: http://www.ht.com.

Horton, B.J. (1993). Should student nurse anesthetists be required to administer regional anesthesia? American Association of Nurse Anesthetists 61(5), 497-502.

Jacob, S., Tierney, E. (1997). A dual technique for identification of the epidural space. Anaesthesia (England) 52(2), 141-143.

Kaltenborn, K. F., Reinhoff, O. (1993). Virtual reality in medicine. Methods of Information in Medicine 32, 407-417.

Katz, W.T., Jordan, W. (1994). Atlas of Regional Anesthesia. Simon & Schuster; New York.

Kaufman, A., Hong, L. (1996). 3D virtual colonoscopy. Computer Science Department, SUNY at Stony Brook. WWW: http://www.cs.sunysb.edu/~volvis/colonoscopy.colonoscopy.htm.

Lindberg, D.A.B. (1996). National Library of Medicine to unveil vast potential of "Visible Human ™" project. U.S. Library of Medicine: NIH News Alert. _September 18, 1996. WWW: http://www.nlm.nih.gov/news/press_releases/vhppr.html.

McDonald, J. S. (1995). Virtual reality technology applied to anesthesiology. A Presentation for Medicine meets virtual reality III. WWW: http://www.osc.edu/ News/MadVRIII.1.95.html.

McDonald, J.S., Rosenberg, L.B. & Stredney, D. (1995). Virtual reality technology applied to anesthesiology. Medicine Meets Virtual Reality III: Interactive Technology & the New Paradigm for Healthcare, Jan 19-22, 1995, San Diego, CA.

National Library of Medicine (1990). Visible human project. Bethesda, Maryland.

Netter, F. H. (1989). Atlas of Human Anatomy. Ciba-Geigy Corp., Summit, New Jersey.

O'Brien, J. F., Ezquerra, N. F. (1996). Modeling, imaging and visualization: Interactively deformable models for surgery simulation. Georgia Institute of Technology. WWW: http://www.cc.gatech.edu/gvu/visualization/surgsim/surgsim-old.htm.

Ohio Supercomputer Center (1996). Biomedical applications research initiative: Virtual simulation of regional anesthesia. WWW: http://www.osc.edu/Biomed/vsra.html.

Ota, D., Loftin, B., Saito, T., Lea, R., Keller, J. (1995). Virtual reality in surgical education. . Computers in Biology and Medicine 25(2), 127-137.

Papert, S. (1980). Mindstorms. Basic Books, New York.

Pimentel, K., Teixeira, K. (1995). Virtual reality: Through the new looking glass. McGraw-Hill: New York.

Pinciroli, F., Valenza, P. (1995). An inventory of computer resources for the medical application of virtual reality. . Computers in Biology and Medicine 25(2), 115-125.

Robb, R.A. (1996). Computer (virtual) endoscopy: Development and evaluation using the Visible Human ™ datasets. The Visible Human ™ Project Conference, National Library of Medicine.

Rosenblum, L. (1996). Responsive workbench. Naval Research Laboratory. WWW: http://www.ait.nrl.navy.military/vrlab.

Satava, R. M. (1994). Emerging medical applications of virtual reality: A surgeon's perspective. Artificial Intelligence in Medicine 6, 281-288.

Saunders, J.B. (1950). The Illustrations from the Works of Andreas Vesalius of Brussels. Dover Publications; New York.

Sausville, D. (1996). Segmentation and classification. Center for Human Simulation at the University of Colorado Health Sciences Center. WWW: http://www.uchsc.edu/sm/chs.

Schiemann, T. (1996). The Visible Human ™ within the Voxel-Man framework. The Visible Human ™ Project Conference, National Library of Medicine.

Schiemann, T., Nuthmann, J., Tiede, U., Hohne, K.H. (1996). Generation of 3D anatomical atlases using the Visible Human ™. Computer Applications to Assist Radiology, Proceedings SCAR'96. Symposia Foundation, Carlsbad, CA, 62-67.

Spiro, R.J., & Jehng, J.C. (1990). Cognitive Flexibility and Hypertext: Theory and Technology for the Nonlinear and Multidimensional Traversal of Complex Subject Matter. Cognition, Education and Multimedia: Exploring Ideas in High Technology. Lawrence Erlbaum Associates, Hillsdale, NJ.

Vygotsky, L. (1978). Mind in Society: The Development of Higher Psychological Processes. Harvard University Press, Cambridge, MA.

Weghorst, S. (1994). Virtual reality in medicine (editorial). Artificial Intelligence in Medicine 6, 277-279.

Bibliography

Bushyhead, A.L. (1996) abstract. Cross-sectional anatomy education and the visible human datasets. The Visible Human ™ Project Conference, National Library of Medicine.

Corning, J.L. (1885). Spinal anesthesia and local medication of the cord. New York Medical Journal(42), 483-485.

Halstead, W.S. (1885). Practical comments on the use and abuse of cocaine; suggested by its invariably successful employment in more than a thousand minor surgical operations. New York Journal of Medicine (42), 294.

Hohne, K.H., Kikinis, R. (1996). Segmentation of the Visible Human ™ for high quality volume based visualization. Springer-Verlag, 13-22.

Robb, R.A. (1994). Three-Dimensional Biomedical Imaging: Principles and Practice. VCH Publishers; New York.

Satava, R. M. (1995). Virtual reality and telepresence for military medicine. Computers in Biology and Medicine 25(2), 229-236.

Spitzer, V.M., Whitlock, D.G. (1996). The Visible Human ™ male. WWW: http://www.uchsc.edu/sm/chs/vhm.html. University of Colorado Center for Human Simulation.

Spurgeon, T., Alciatore, D. (1996). Virtual anatomy project. Colorado State University. WWW: http://www.vis.colostate.edu/library/gva/gva.htm.

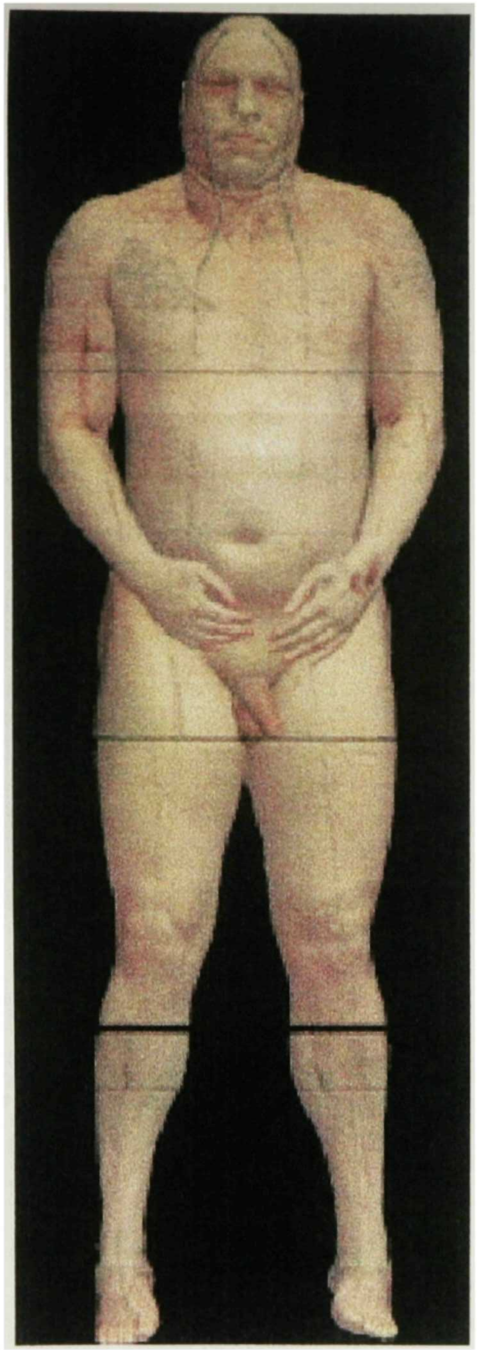


Fig. 1: Visible Human Male. Skin reconstructed from serial cross-sections.

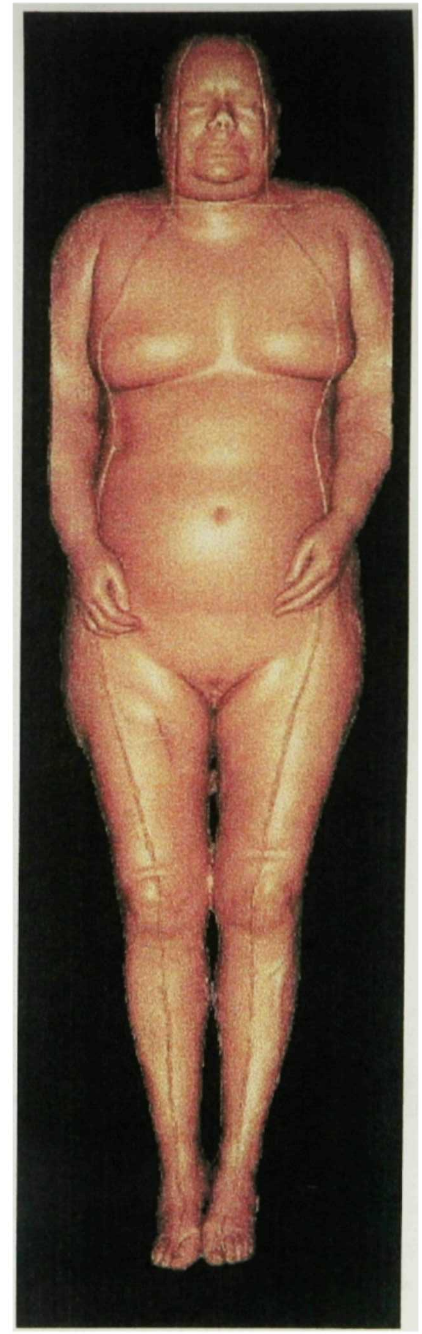


Fig. 2: Visible Human Female. Skin reconstructed from serial cross-sections.

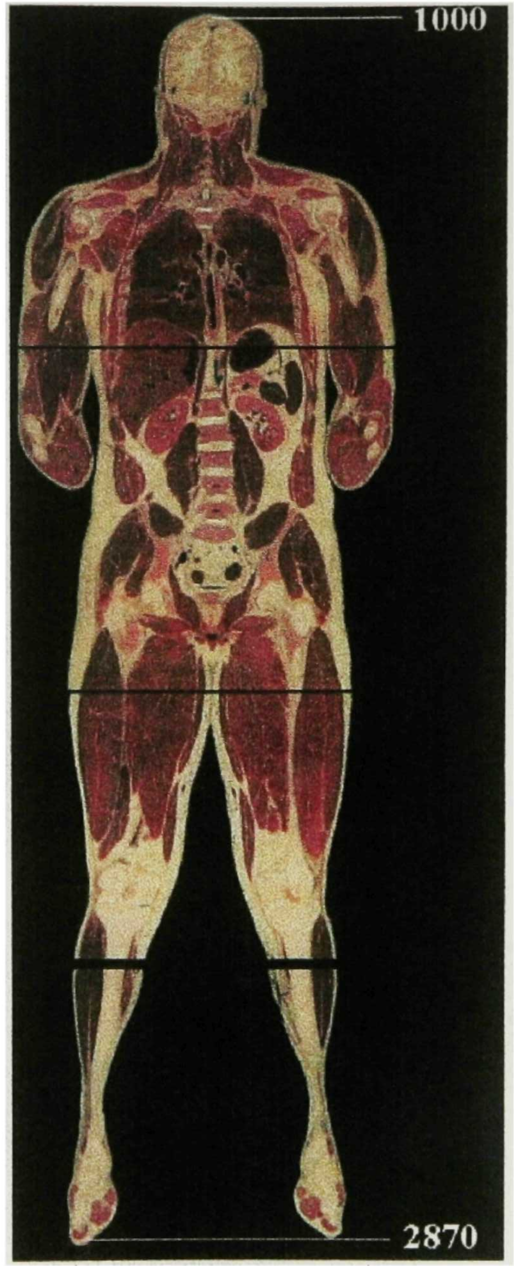


Fig. 3: Male coronal view reconstructed from computer compilation of original cross-sections. Numbers indicate approximate plate numbers. Lines across image indicate original block cuts.
(Ref: University of Colorado online, http://www.uchsc.edu/sm/chs/browse_m.html).

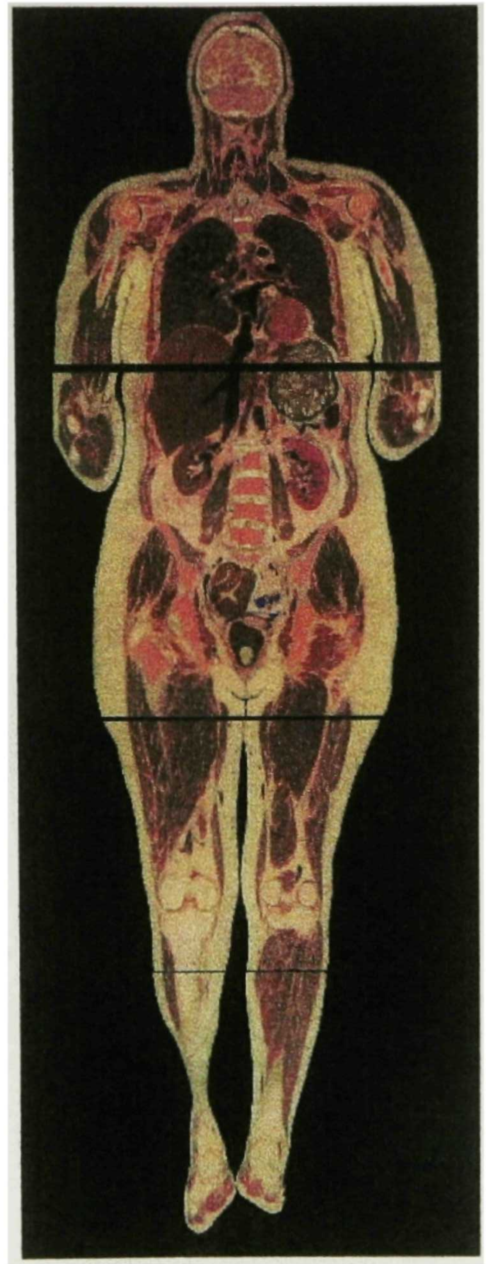


Fig. 4: Female coronal view computer reconstruction. Lines across image indicate original block cuts.
(Ref: University of Colorado online, http://www.uchsc.edu/sm/chs/browse_m.html).

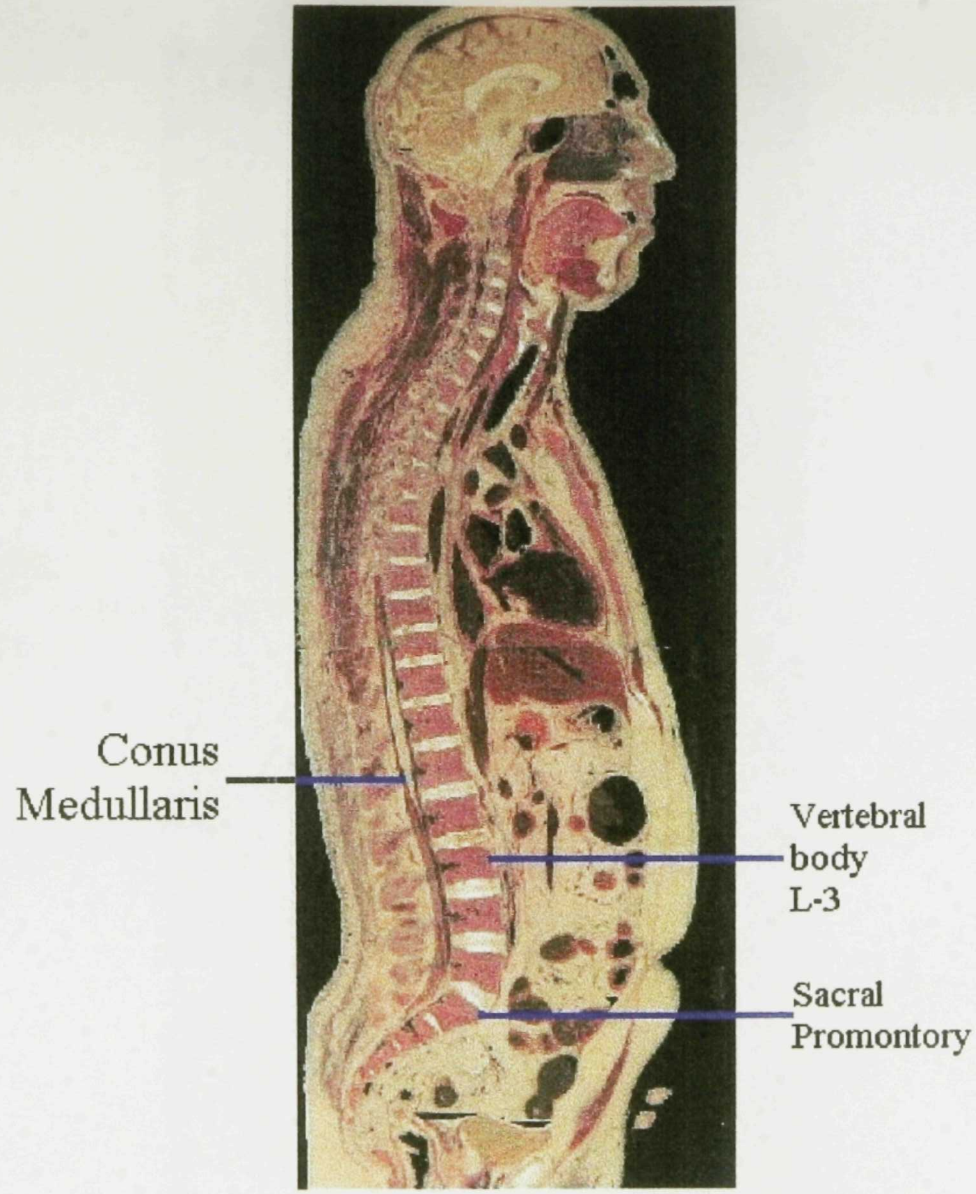


Fig. 5a: Close-up of one sagittal view showing lowest level of spinal cord. (Ref: Northeast Parallel Architectures Center, Syracuse University. http://www.uchsc.edu/sm/chs/browse_html).

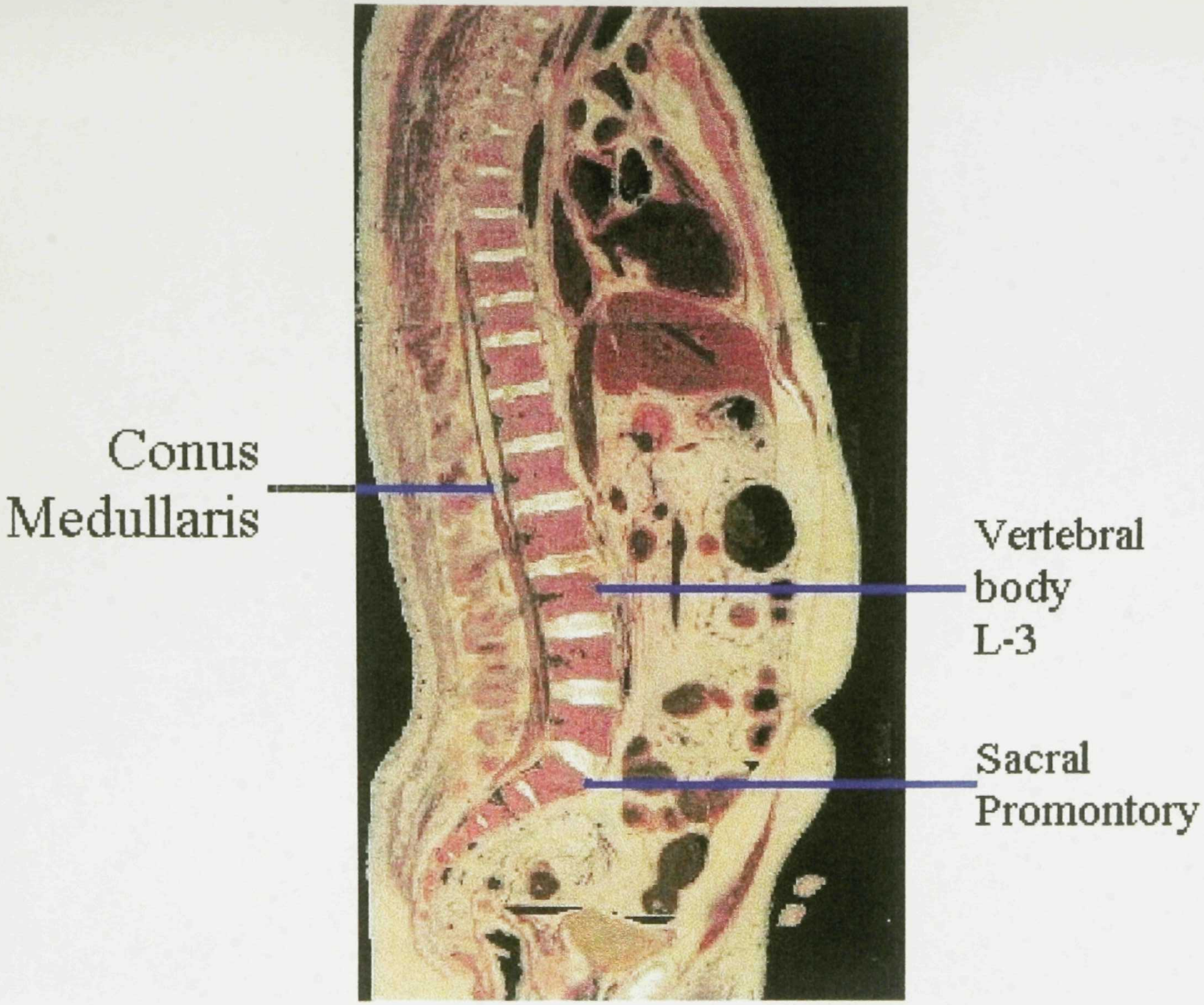


Fig. 5a: Close-up of one sagittal view showing lowest level of spinal cord.
(Ref: Northeast Parallel Architectures Center, Syracuse University.
http://www.uchsc.edu/sm/chs/browse_html).

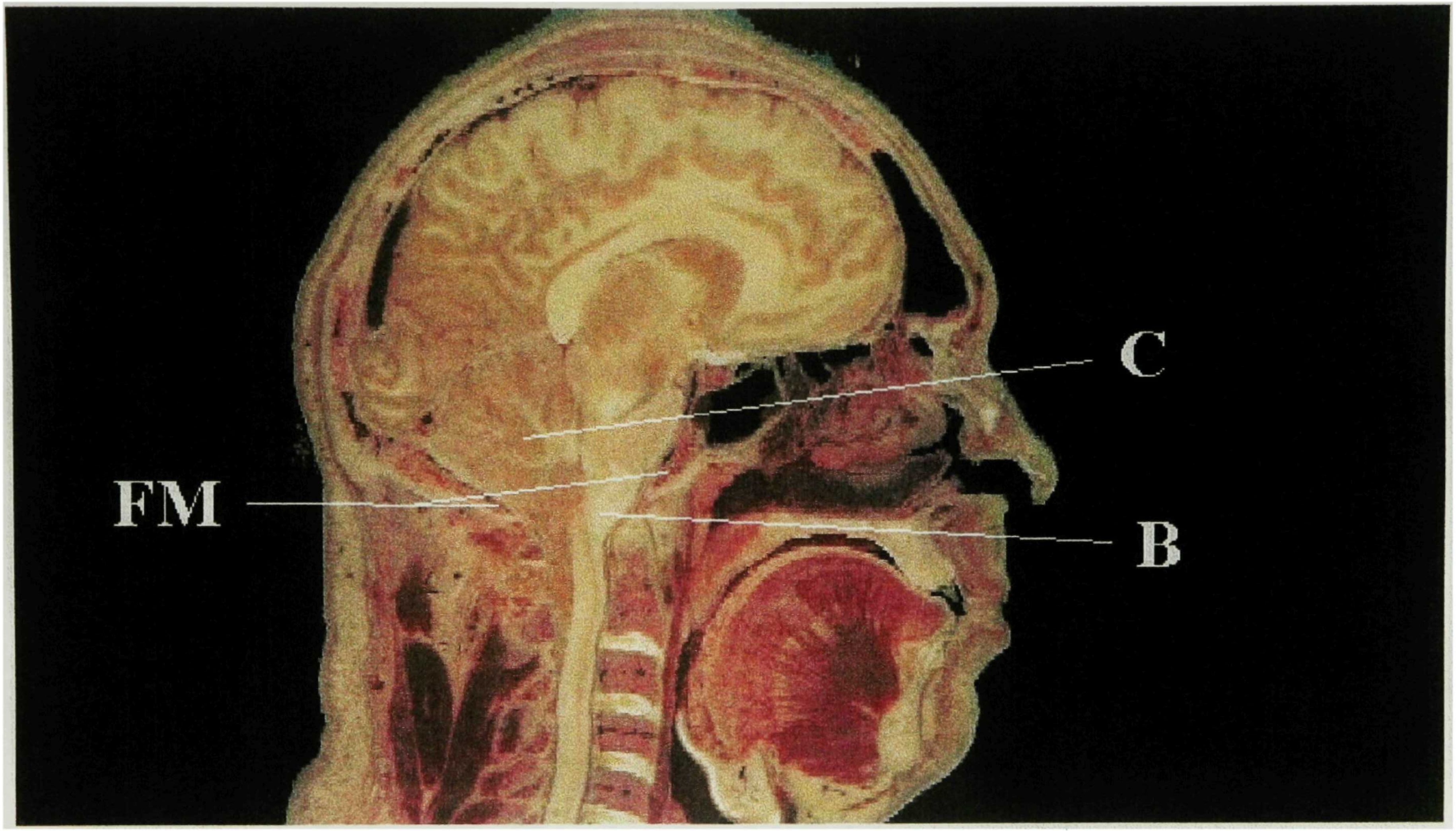


Fig. 6: Male sagittal section computer reconstruction from original cross-sections. Note caudad movement of cerebellum (C), and brainstem (B) through foramen magnum (FM).
(Ref: Northeast Parallel Architectures Center, Syracuse University).

Fig. 7: Original high-resolution color plate of Visible Human Female. Level is lower thoracic cord. Posterior at top of photograph. (Ref: National Institute of Health).

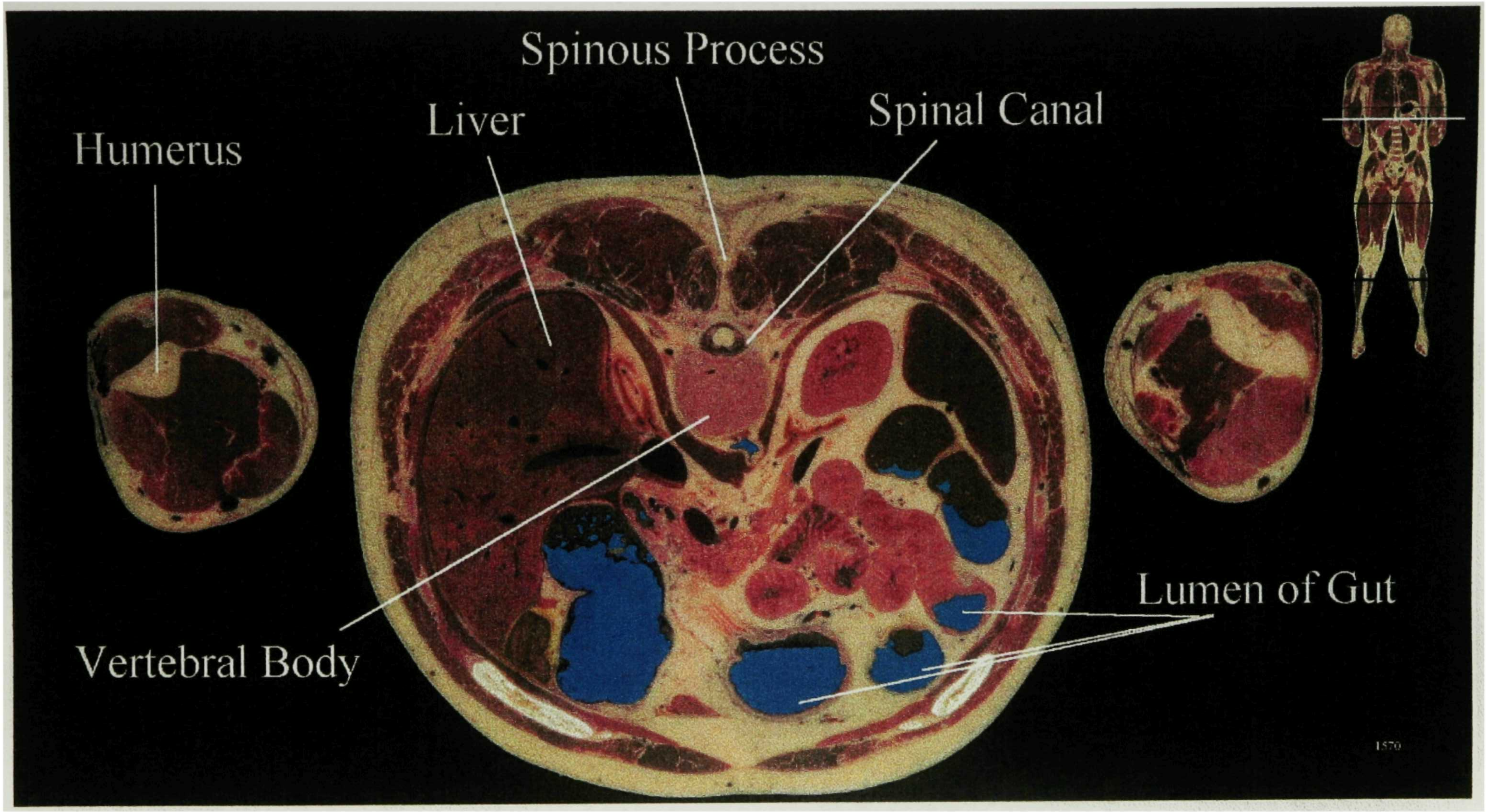


Fig. 8: Male transverse section through lower thoracic cord.

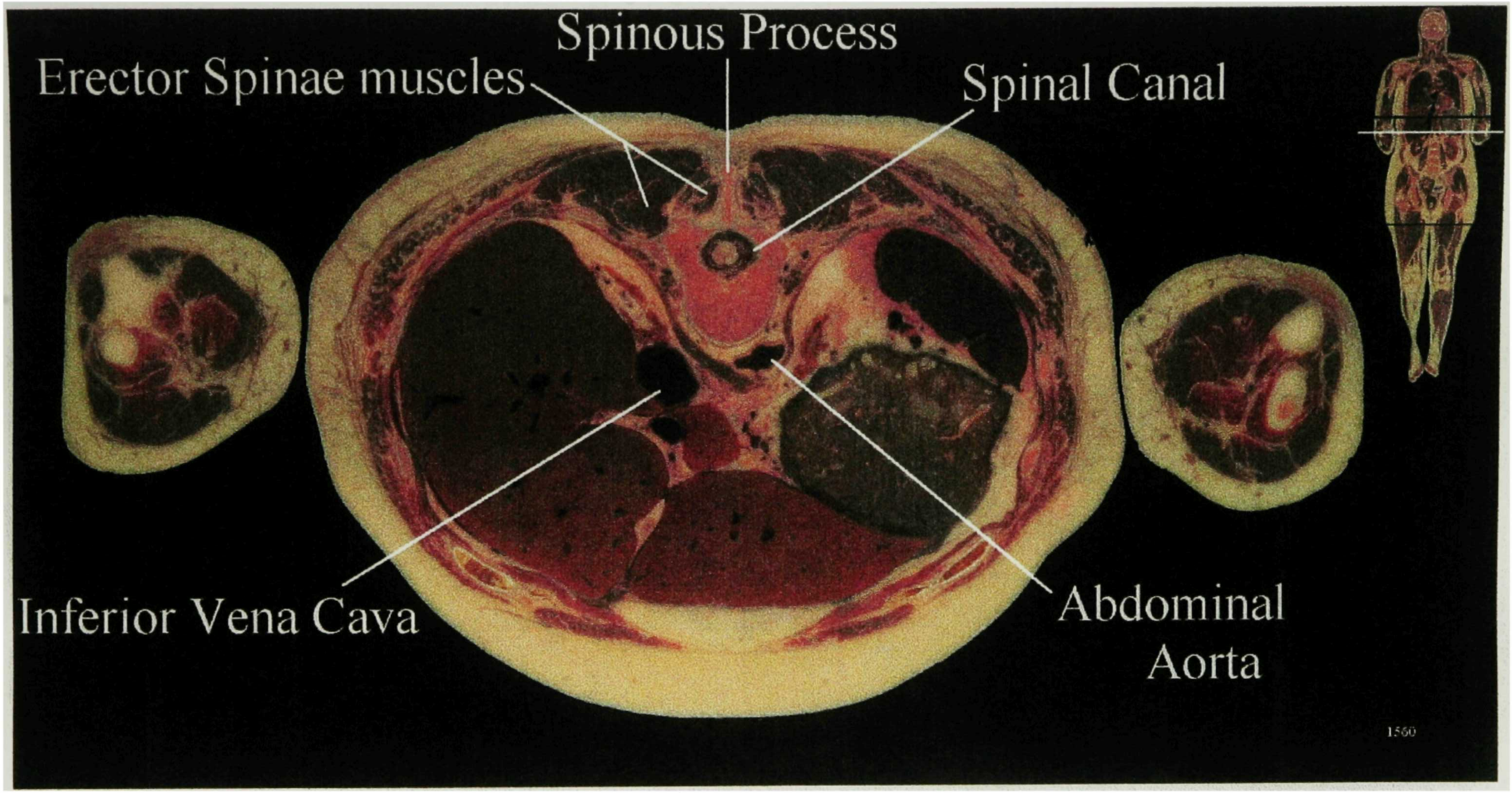


Fig. 9: Female transverse section through lower thoracic cord.

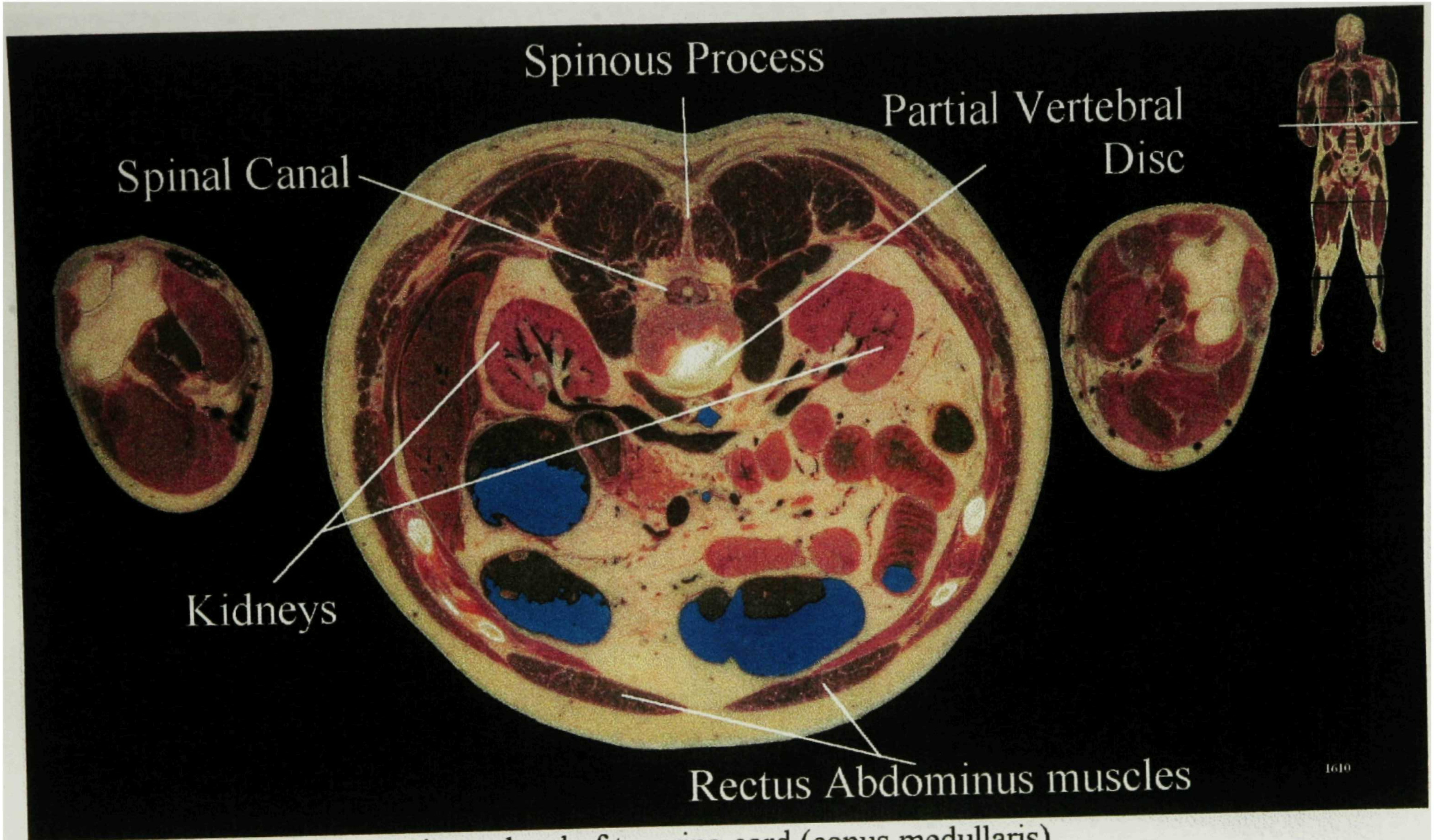


Figure 10: Male cross-section at level of tapering cord (conus medullaris).

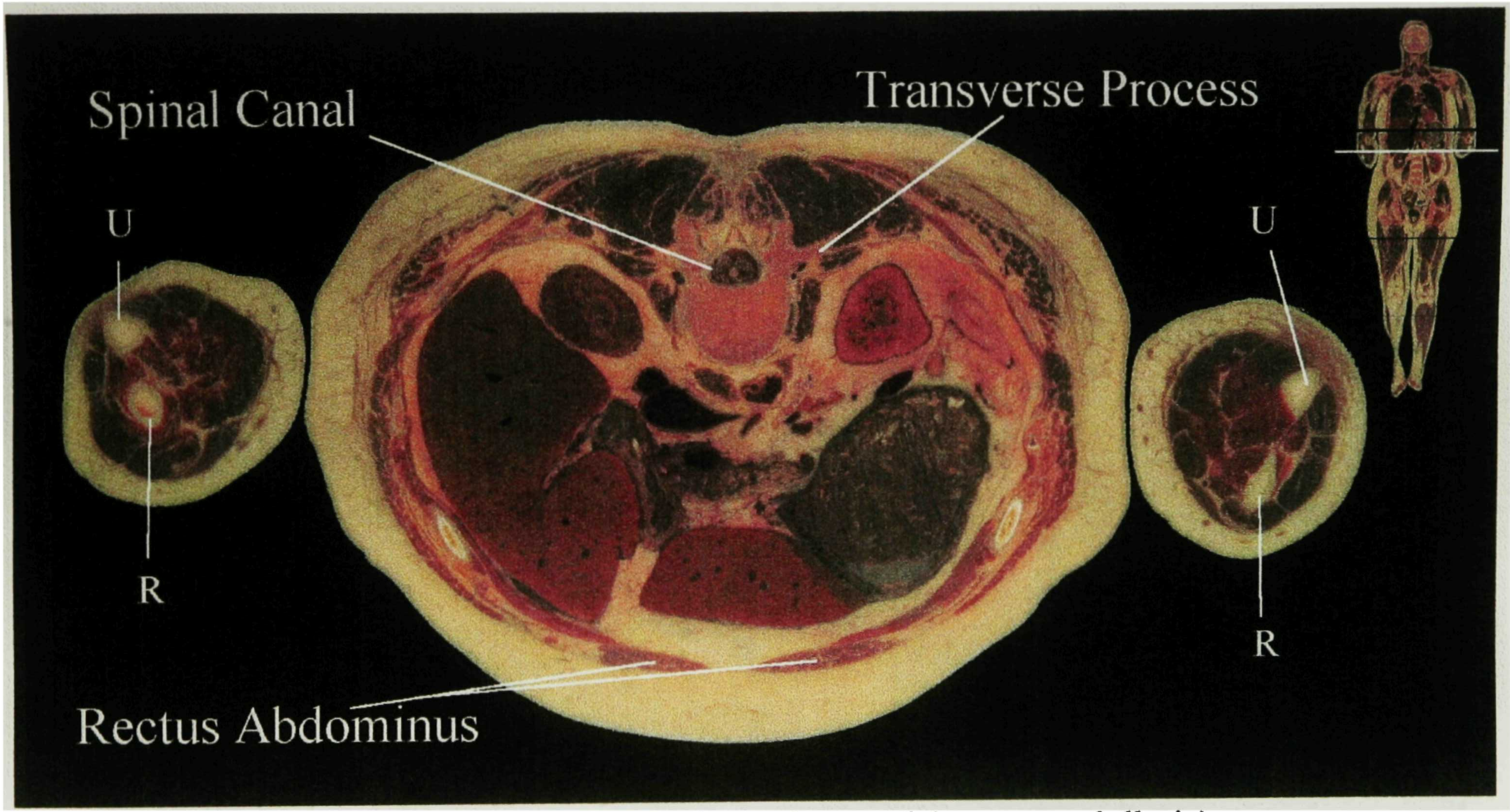


Figure 11: Female cross-section at level of tapering cord (conus medullaris).
Key: Radius (R), Ulna (U).

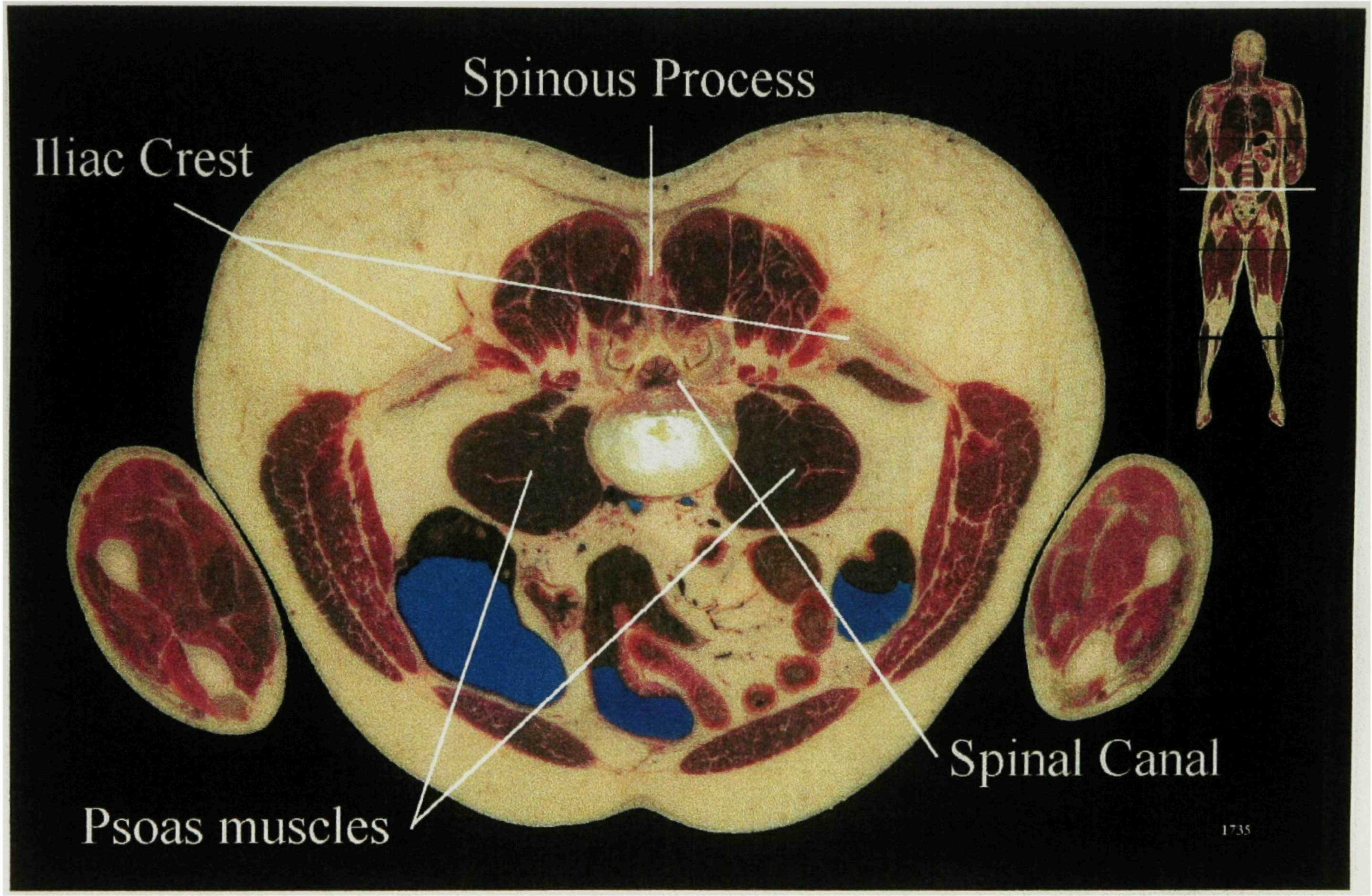


Figure 12: Male cross-section at level of Iliac Crest.

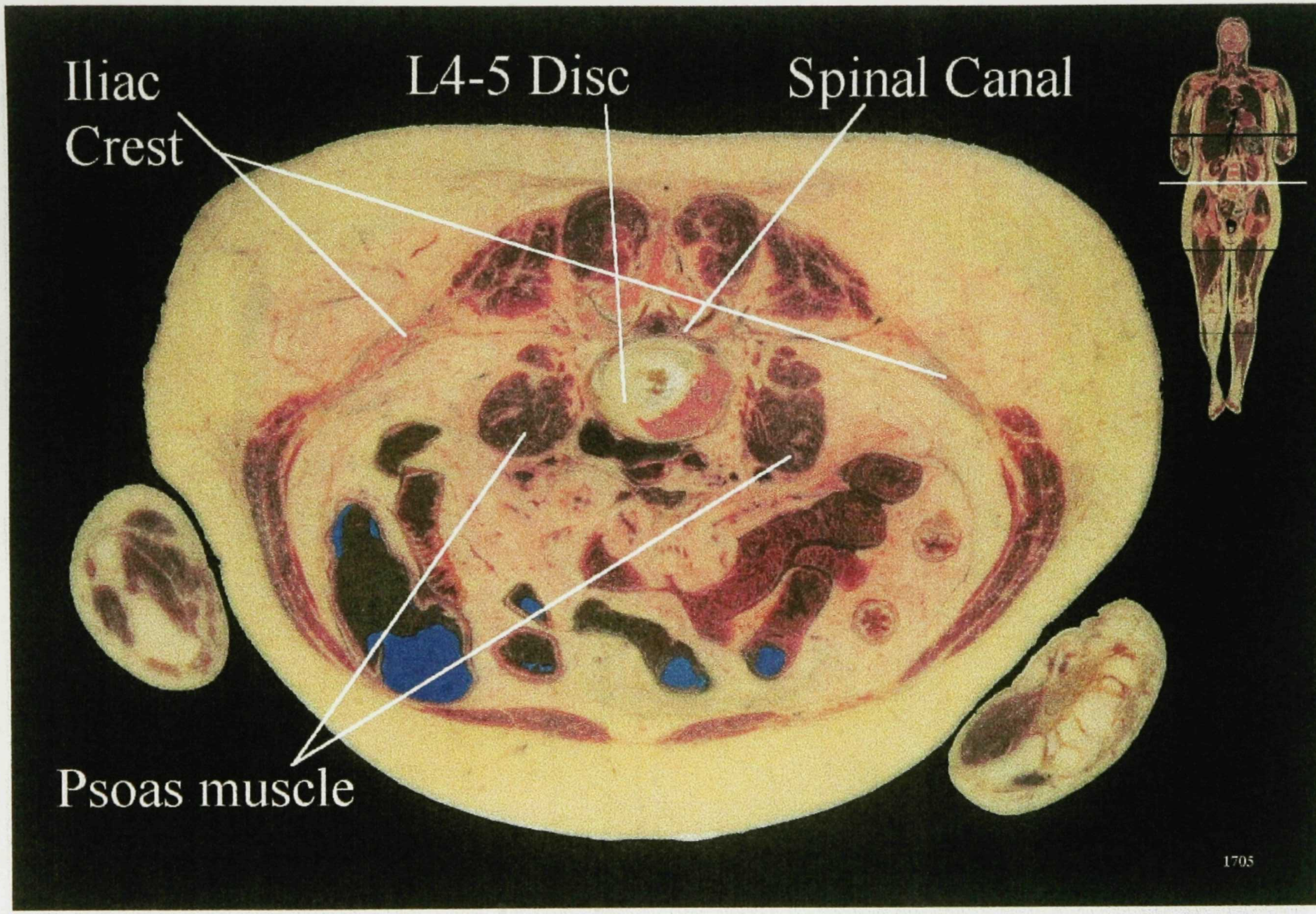


Figure 13: Female cross-section at level of Iliac Crest.

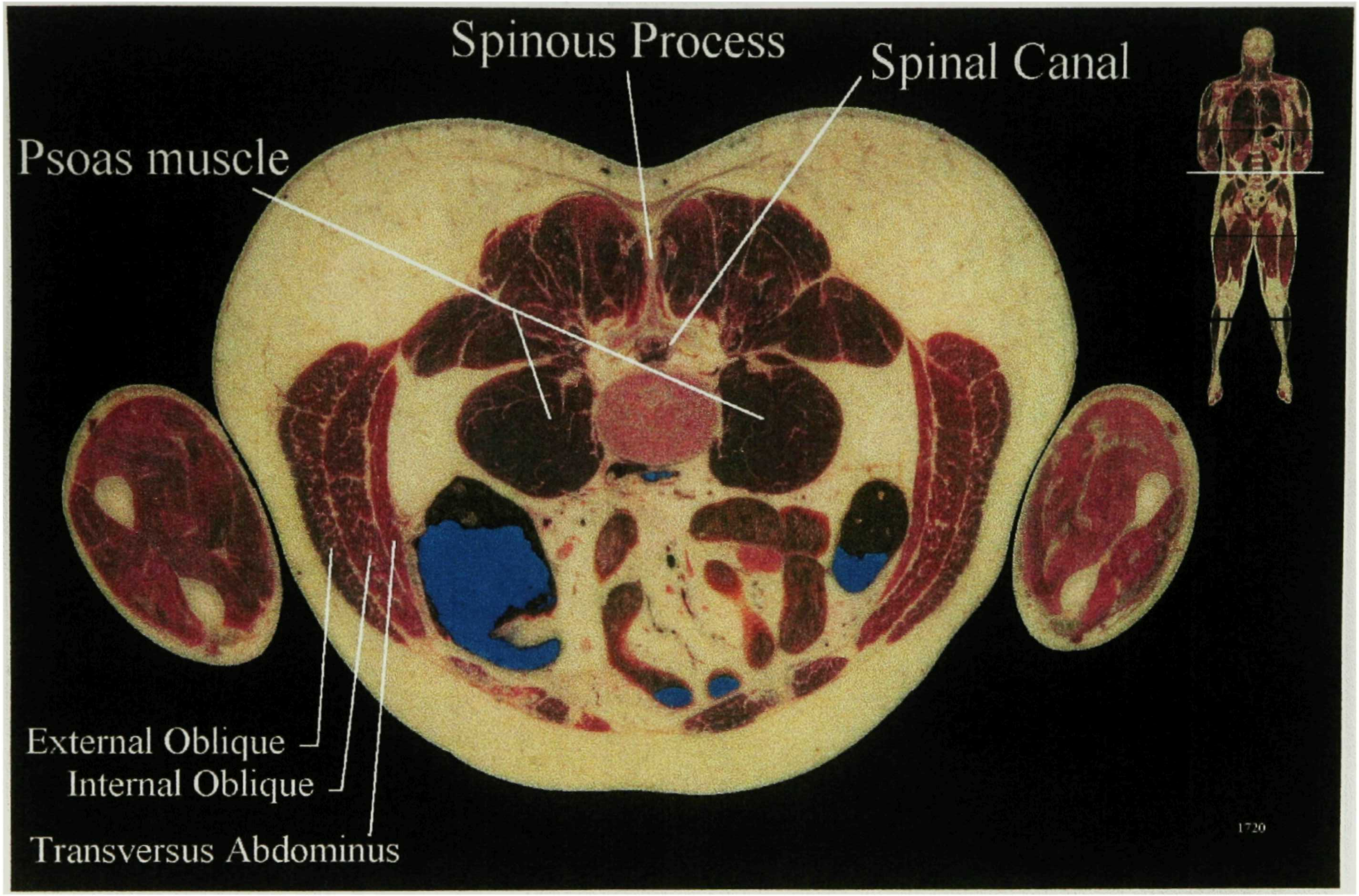


Fig. 14: Male cross-section at L3-4 interspace.

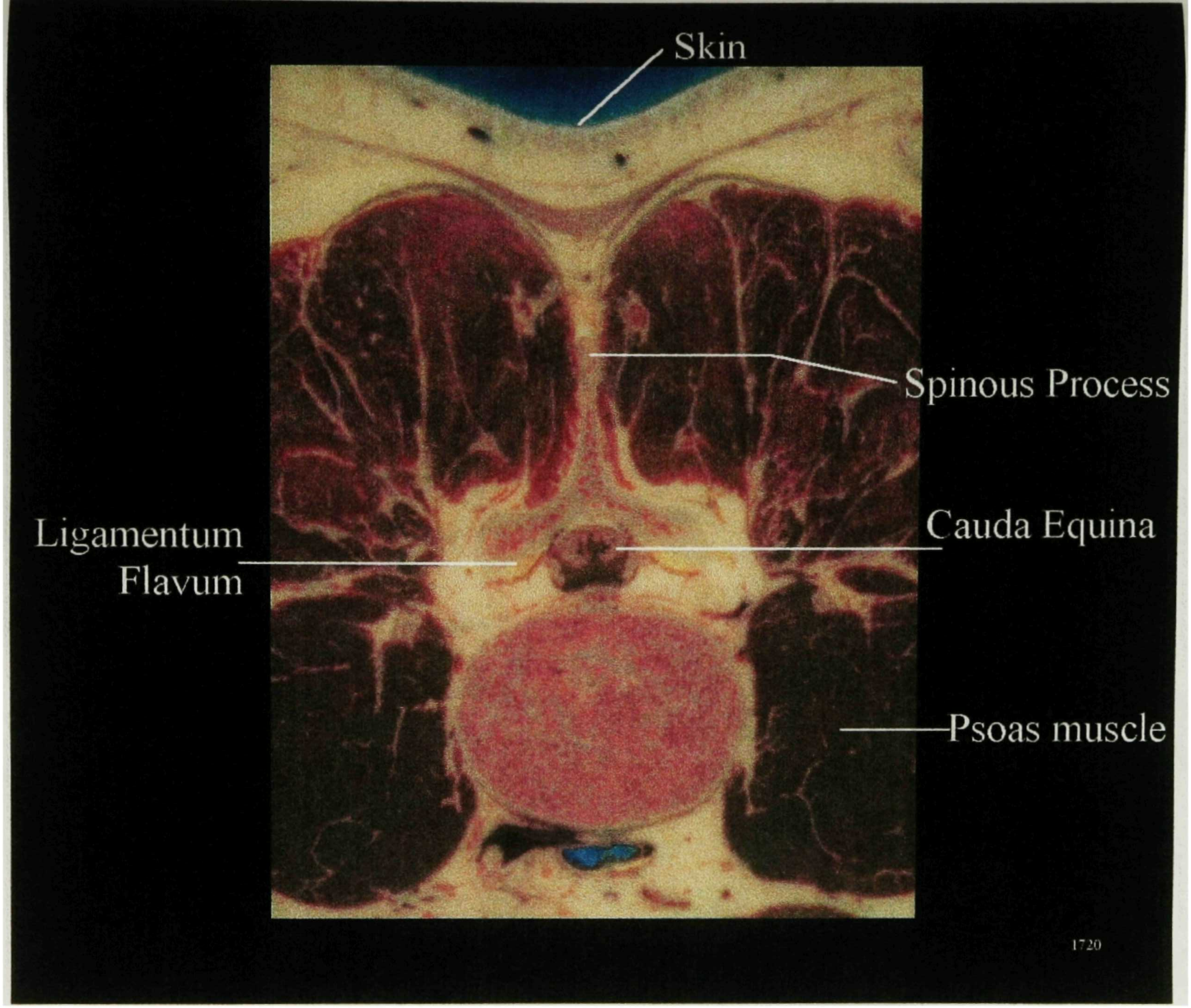


Fig. 15: Close-up of male cross-section at L3-4 interspace.

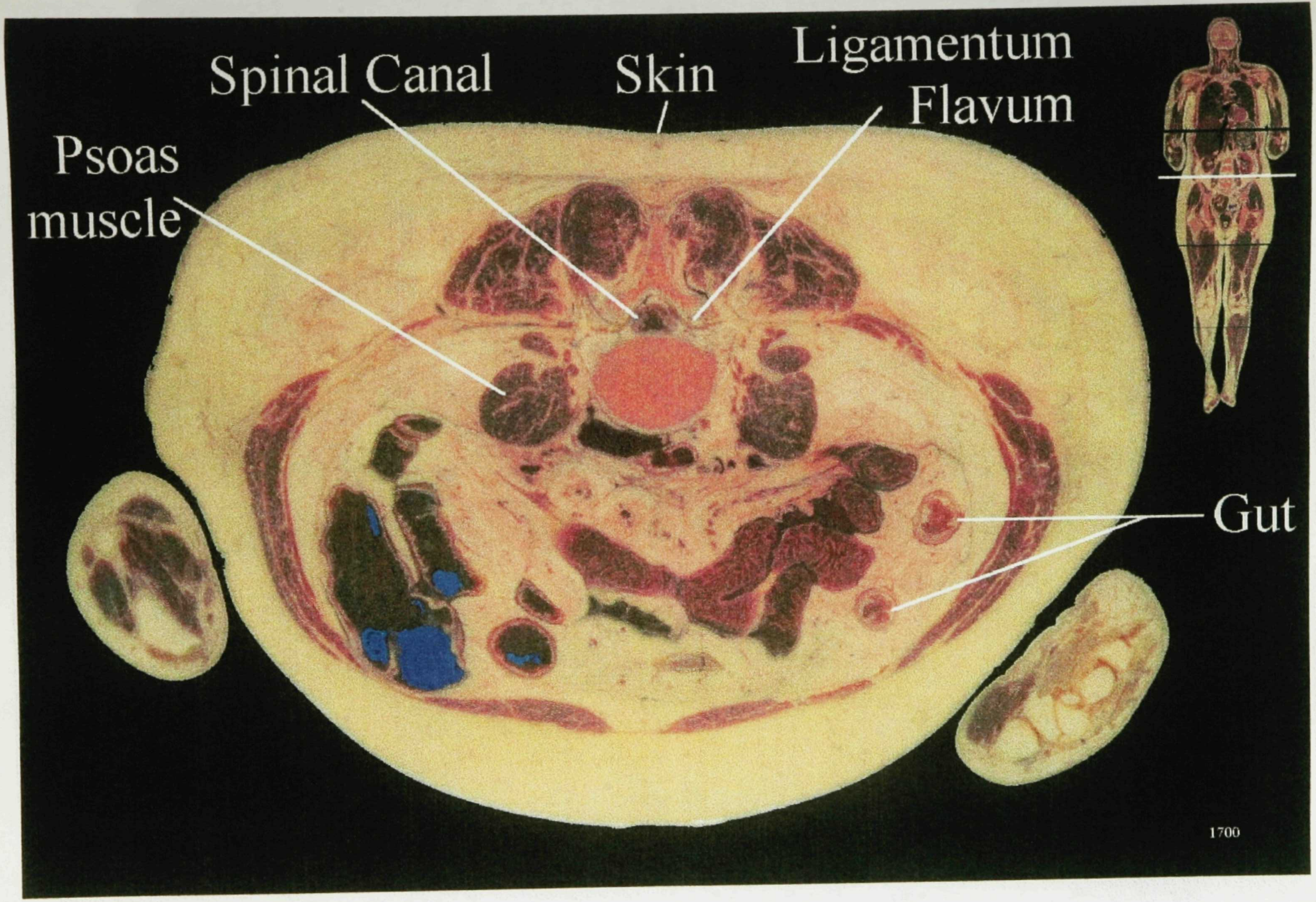


Fig. 16: Female cross-section at L3-4 interspace.

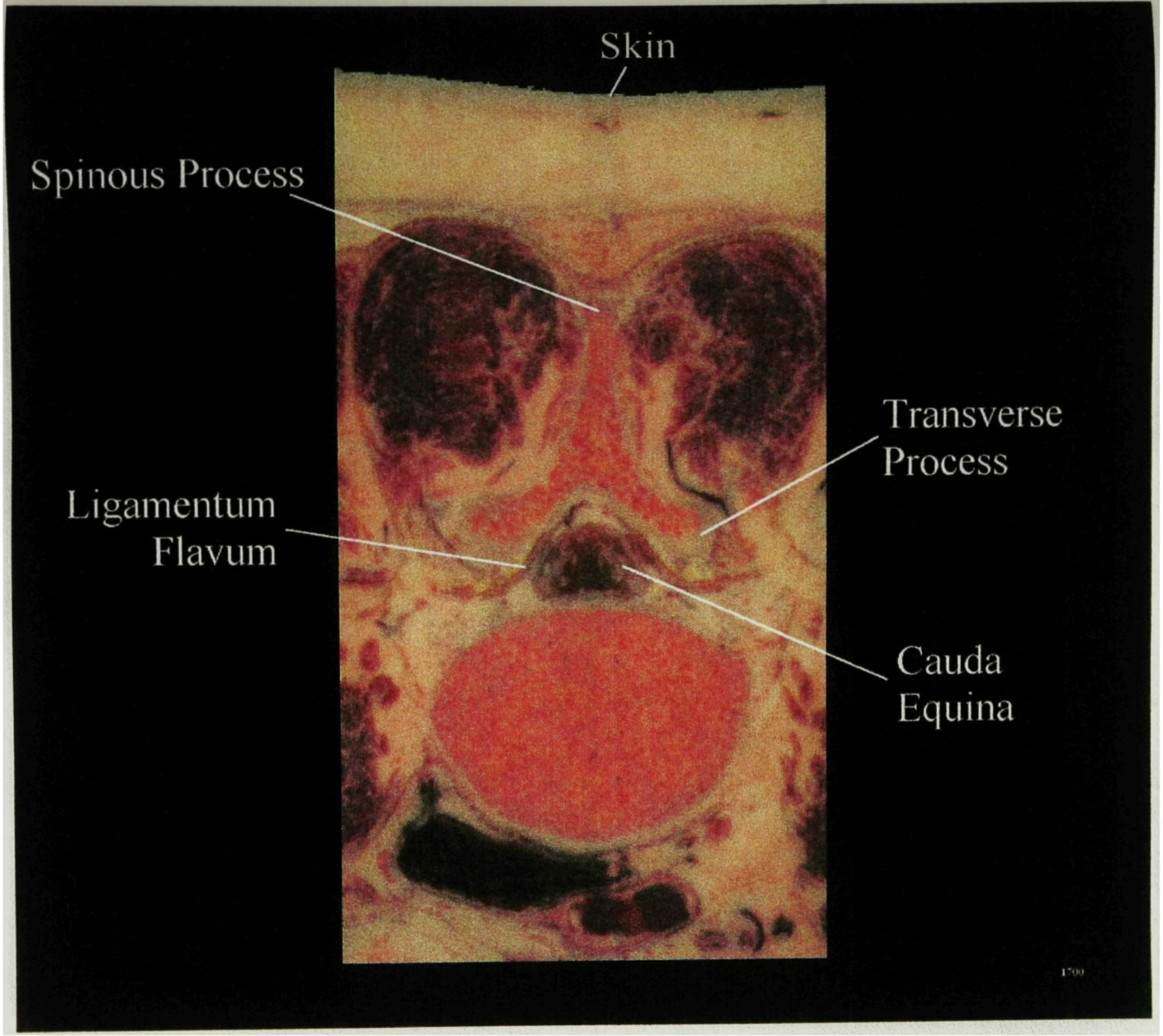


Fig. 17: Close-up of female cross-section at L3-4 interspace.

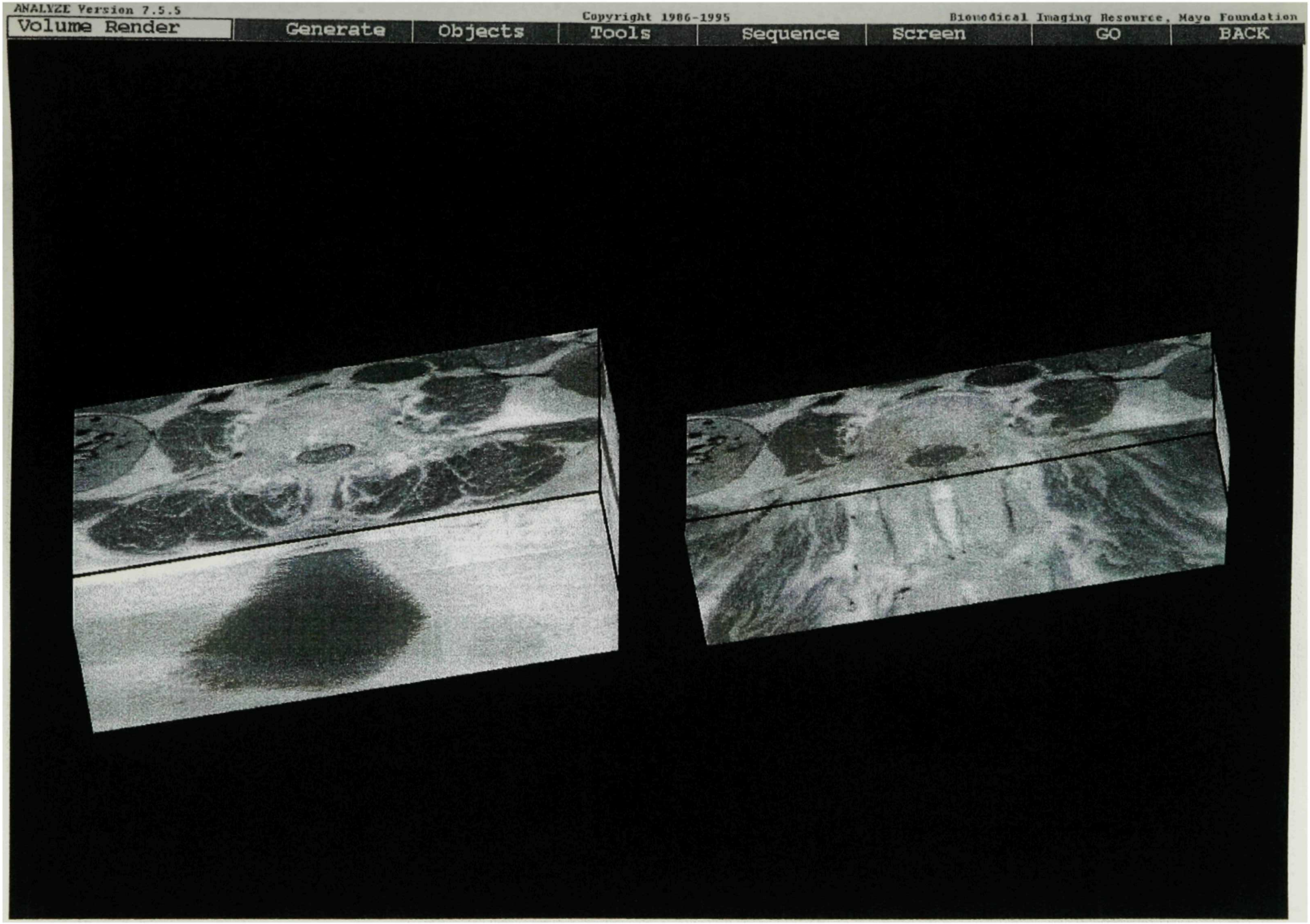


Fig. 18: Three-Dimensional Reconstructions of VHF Cross-Sections.

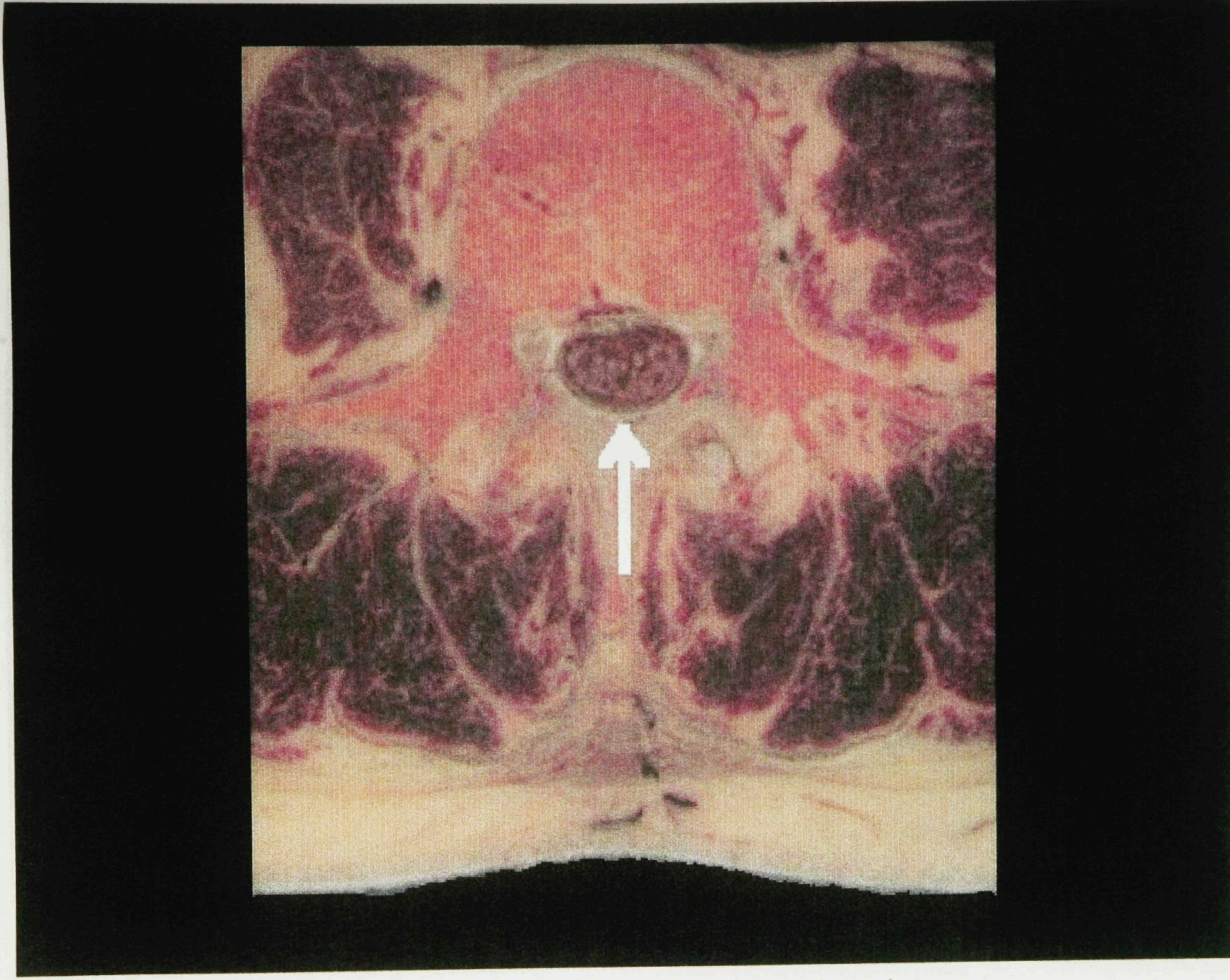


Fig. 19: Close-Up of Cross-Section with No Epidural Space Present (arrow).

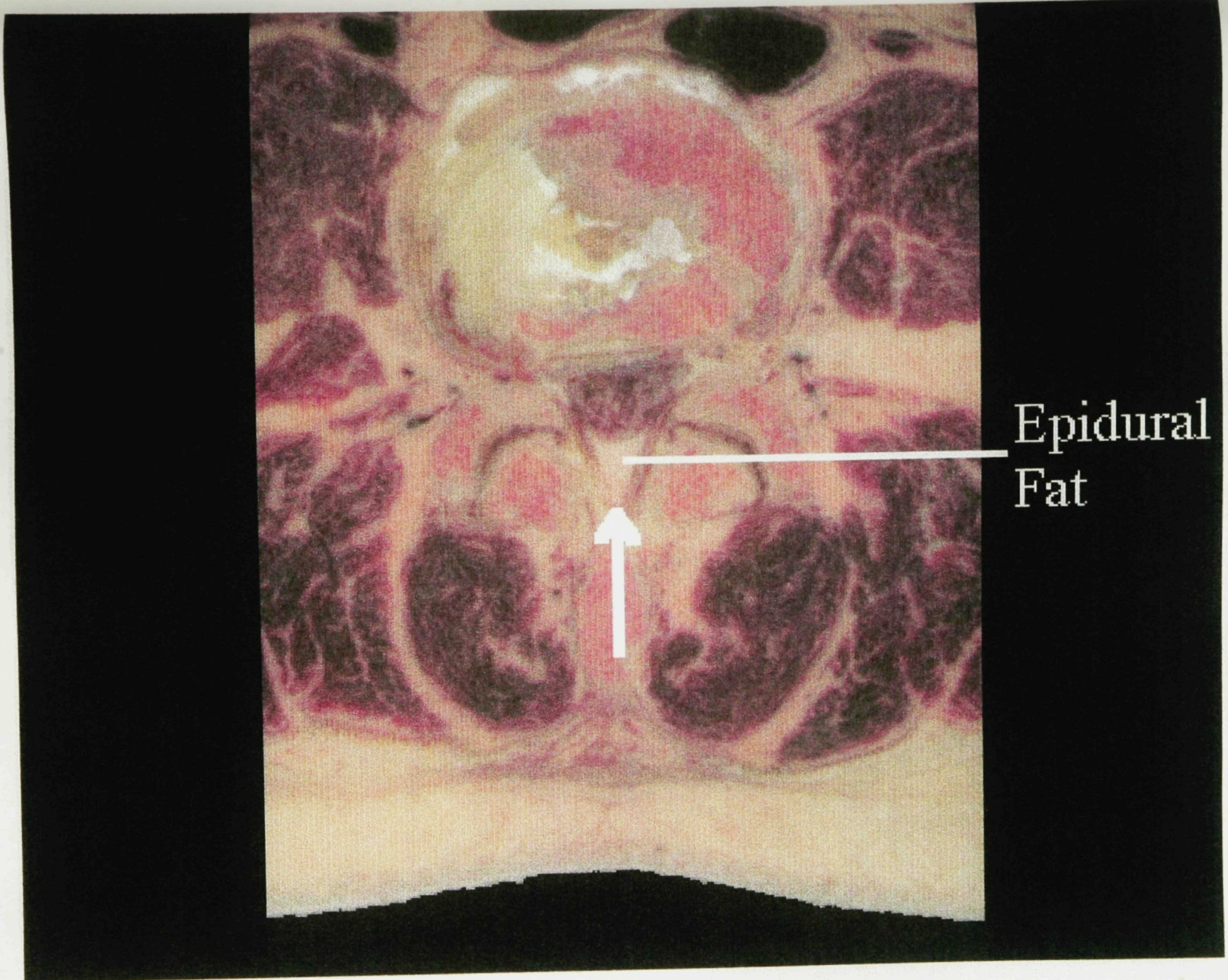


Fig. 20: Close-Up of Cross-Section with Epidural Space Present (arrow).

APPENDICES

Appendix A. Analyze ™ License Agreement

Appendix B. Visible Human ™ License Agreement

Appendix C. Analyze ™ Software Specifications

Appendix D. Software for Volume Visualization or 3-D Reconstruction

Appendix E. Procedures for Downloading VH Images from NIH (Macintosh)

Appendix F. High Techsplanations Inc. Simulations

Analyze™ License Agreement

Appendix A

Visible Human License Agreement

Appendix B

MEMORANDUM

Date: 24 July 1996
TO: Dean SOM, Legal Counsel USUHS
PHONE:
FAX:
FROM: James G. Smirniotopoulos, M.D.
Professor and Chairman
Department of Radiology and Nuclear Medicine
Uniformed Services University of the Health Sciences
4301 Jones Bridge Road
Bethesda, MD 20814

USUHS: TEL: 301-295-3145 FAX: 301-295-3893
INTERNET: jsmirnio@bob.usuf2.usuhs.mil
-or- AXONMAN@AOL.COM

SUBJECT: Visible Human Project

The Department of Radiology and Nuclear Medicine, in conjunction with the Department of Anatomy (Dr. Rollag) and the Graduate School of Nursing (Dr. Rigamonti) are requesting to use the illustrative material from the VISIBLE HUMAN PROJECT of the National Library of Medicine. This material can be downloaded free of charge, and can be incorporated into education projects and products developed by the University, persuant to the attached agreement. Please review the attached agreement (from the NLM) so that we can have concurrence to move forward with this project.

DEPARTMENT OF HEALTH & HUMAN SERVICES

Public Health Service

National Institutes of Health
National Library of Medicine
Bethesda, Maryland 20894

September 5, 1996

James G. Smirniotopoulos, M.D.
Professor & Chairman, Dept. of Radiology & Nuclear Medicine
Uniformed Services University of the Health Sciences
4301 Jones Bridge Road
Bethesda, Maryland 20814

Dear Dr. Smirniotopoulos:

Your Visible Human Data Set License Agreement has been approved by the National Library of Medicine. You may download individual cross-sections from the Visible Human Data Set from our Visible Human FTP site. This site is connected to the Internet by a T-3 (45 megabit) line.

FTP site: vhnet.nlm.nih.gov (130.14.35.50)

For the Visible Human Male data set:

Account: vhpmale

Password: vis!male

For the Visible Human Female data set:

Account: vhpfemale

Password: vis!female

Each file is individually compressed in a UNIX-Z compression format. UNIX systems should have a utility to do the decompression. For PCs a program called COMP430D and for Macs a program called MacCompress 3.2 is available from the Visible Human FTP site, "utilities" section, to do the decompression.

I have found that the easiest way for me to explain how to read each of the data types is to explain how they would be read if you were using Photoshop 3.0. Under RAW input format, the values from the following table would be entered:

	Anatomy	CT	MR
Header	0	3416	7900
Width	2048	512	256
Height	1216	512	256
Channels	3	2	2
Interlaced		X	X

This will allow you to see the anatomy images. The CT and MR images will appear as a black screen. For CT and MR, set the "Mode" to "Greyscale". Then set "Image" to "Adjust" to "Auto". The CT and MR images will now be visible.

The male data set is also available to NLM licensees on 4mm or 8mm tape from the National Technical Information Service (N.T.I.S.). An order form will be sent to you along with your signed copy of the Agreement. The availability of the female data set will be announced shortly.

Please be advised that a Visible Human Project logo is now available for your use in crediting NLM for the data set. A .gif file, vhplogo.gif, of the logo can be downloaded from the Visible Human FTP site, "utilities" section. The height of the logo when printed should be at least 1 inch.

Your continued interest in the Visible Human Project is greatly appreciated. Comments concerning any aspect of the data set would be welcome. Please e-mail your suggestions to me at ackerman@nlm.nih.gov.

Sincerely,

Michael J. Ackerman, Ph.D.
Project Officer
The Visible Human Project

AGREEMENT FOR

USE OF IMAGES FROM VISIBLE HUMAN DATA SET

Made this 23 day of AUGUST, 1996 by and between the National Library of Medicine, Department of Health and Human Services (hereinafter referred to as "NLM") and ______________________ (hereinafter referred to as "RECIPIENT").

WHEREAS, the NLM was established by statute in order to assist the advancement of medical and related sciences, and to aid the dissemination and exchange of scientific and other information important to the progress of medicine and to the public health, (section 465 of the Public Health Service Act, as amended (42 U.S.C. section 286) and to carry out this purpose has been authorized to develop the Visible Human Data Set (VHD) as a first project in establishing a digital medical image archive at NLM;

WHEREAS, the NLM's Visible Human Project™ has produced new digital image data sets (VHD products) that are now ready to be used in a variety of settings to determine their current utility and obtain feedback on useful enhancements;

WHEREAS, RECIPIENT desires to use the VHD products at its sole risk and at no expense to NLM,

NOW THEREFORE, it is mutually agreed as follows:

1. The NLM hereby grants a nonexclusive right to RECIPIENT to use the VHD products and incorporate them in computer applications or systems designed to improve access to those images or to biomedical information of any type. A description of the proposed applications or systems is attached.

2. RECIPIENT may distribute computer applications containing the VHD products to other institutions and individuals free of charge or at such reasonable prices as RECIPIENT determines provided, however, that the RECIPIENT obtains agreement from such institutions and individuals that they will be bound by the terms of this Agreement. No charges, usage fees or royalties will be paid to NLM. RECIPIENT shall acknowledge NLM and the Visible Human Project™ as its source of the VHD data[1] in a suitable and customary manner, but may not in any way indicate that NLM has endorsed RECIPIENT or its products.

3. RECIPIENT shall not distribute VHD products or subsets of these products except as an integral part of computer applications developed by RECIPIENT.

4. RECIPIENT agrees to demonstrate to NLM any applications in which it is using the VHD products prior to distributing the application(s). RECIPIENT agrees to provide specific information to NLM regarding how VHD products are used in its application(s), the users and usage of any application containing the VHD products, any difficulties encountered in using the VHD products, and changes or enhancements to the VHD products that would make them more useful to RECIPIENT and its user groups. RECIPIENT shall provide NLM with a copy of any applications incorporating the VHD products and agrees that NLM shall have an irrevocable, paid up, non-exclusive license under the U.S. patent and copyright laws, as the case may be, to use, reproduce, prepare derivative works, and perform the applications, for Government purposes.

An anatomical data set developed under a contract from the NLM by the Departments of Cellular and Structural Biology, and Radiology, University of Colorado School of Medicine.

5. RECIPIENT and/or its users shall be solely responsible for compliance with any third party copyright restrictions; neither NLM nor its Mirror Sites assume any responsibility or liability associated with the RECIPIENT (or any of the RECIPIENT's users) use and/or reproduction of copyrighted material.

6. RECIPIENT must inform its users that VHD products are provided on an interim basis and may be modified substantially by NLM in subsequent versions.

7. NLM makes no claim that the VHD products encompass all data collected during or associated with this project.

8. The presence in VHD application of data developed by organizations other than NLM does not imply any endorsement by NLM of the data from these organizations.

9. NLM represents that the data comprising the VHD products provided hereunder were formatted with a reasonable standard of care, but makes no warranties express or implied, including no warranty of merchantability or fitness for particular purpose, regarding the accuracy or completeness of the data or that the machine-readable copy is error free. Therefore, RECIPIENT agrees to waive any and all claims against NLM, its Mirror Sites, the Government, and any organizations contributing data to VHD products for liability resulting from errors in data or on the machine-readable copy. NLM reserves the right to change the type and format of its machine-readable data.

10. RECIPIENT understands that there may be substantial changes in the content or format of the subsequent versions of VHD products and that there may be a charge for subsequent versions of VHD products.

11. NLM may offer VHD products to other commercial and noncommercial organizations without accounting to RECIPIENT.

12. This Agreement shall be effective until terminated by either party with 30 days written notice to the other.

13. In the event of termination of this Agreement:

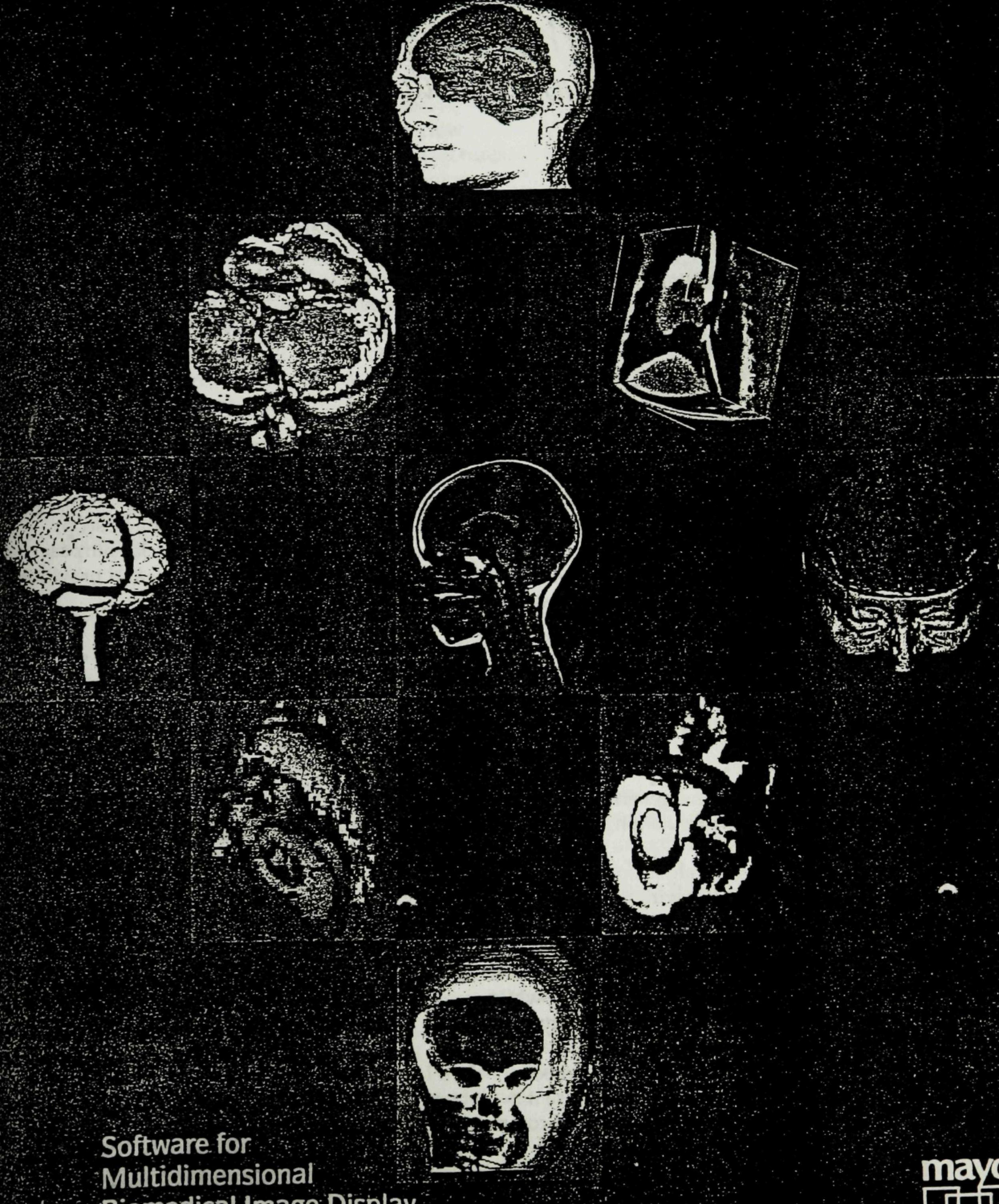
(a) RECIPIENT must enter into a license agreement with NLM for continued use of updated VHD data OR promptly destroy and erase all data in machine-readable form obtained under this Agreement as well as any such data now contained in any derivative files under the RECIPIENT's control.

(b) Neither the Government nor its employees shall be liable or responsible to RECIPIENT in any manner whatsoever for damages of any nature whatsoever arising from the termination of this Agreement or from the use of VHD products.

Analyze ™ Software Specifications

Appendix C

ANALYZE



Software for
Multidimensional
Biomedical Image Display

mayo

Biotechnology Computer Resource
Biodynamics Research Unit
Department of Physiology and Biophysics
Mayo Foundation

INTRODUCTION

The Mayo Biotechnology Computer Resource and Biodynamics Research Unit at the Mayo Clinic have been involved since the early 1970s in the design and implementation of computer-based techniques for the display and analysis of multidimensional biomedical images. The algorithms and programs developed through this program have been integrated into a comprehensive software system called ANALYZE, useful in a variety of multimodality, multidimensional biomedical imaging and scientific visualization applications.

THE ANALYZE SYSTEM

The ANALYZE system features integrated, complimentary tools for fully interactive display, manipulation and measurement of multidimensional image data. It can be applied to data from many different imaging modalities, including CT, MRI, PET, SPECT, ultrasound and digital microscopy. The software runs efficiently on standard UNIX workstations without the need for special-purpose hardware. The software architecture permits systematic enhancements and extensions, and provides an effective shell for rapid prototyping of customized imaging applications.

ANALYZE FEATURES

Five complimentary attributes of ANALYZE make it a uniquely powerful visualization workshop. They are:

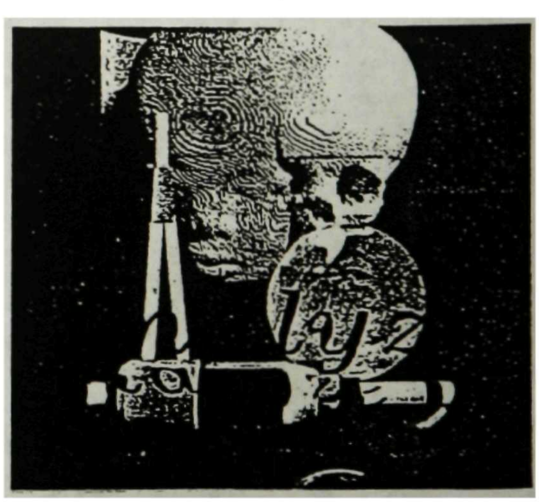
1. It is comprehensive and generic, containing over 60 intelligently and synergistically integrated tools for display, manipulation, and measurement of biomedical images;

2. It has several original algorithms which deal directly and effectively with 3-D and 4-D image data;

3. It is highly operator-interactive; most operations are performed in fractions of a second while preserving accuracy and image quality;

4. It is intuitive and easy to use; surgeons, physicians and basic scientists can use it productively with little knowledge of computers;

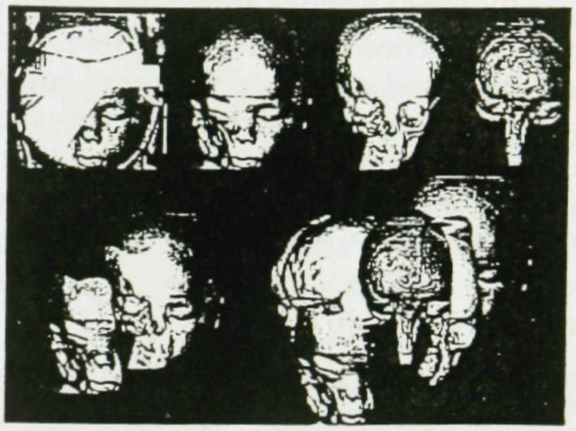
5. It is expandable and transportable; its modular design facilitates expedient enhancements, additions and workstation implementations.



3-D IMAGE GENERATION AND DISPLAY

The ANALYZE system contains powerful tools for interactive computation and display of 3-D images:

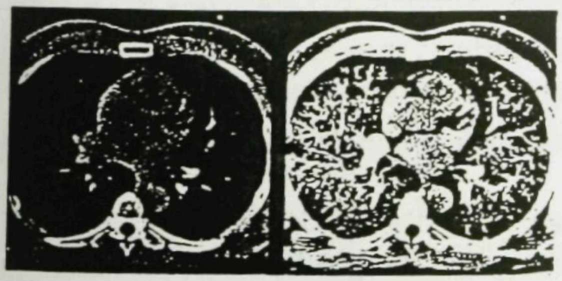
- Volume rendering using ray casting to display 3-D images from volumetric image data. This program contains interactive options for:
  - Depth and gradient shaded surfaces.
  - Variable illumination and angle-of-view.
  - Transparency of overlying surface structures.
  - Multiplanar dissection and subregioning.
  - Numerical projection images (summation, brightest voxel, etc.).
  - Generation of orthogonal and oblique sections depicting intersection with the displayed surface.
  - Manual editing and automatic connection/deletion of objects using region growing.
  - Combined display of multiple segmented objects using different rendering parameters and colors.
  - Interactive spatial manipulations on independent objects (translate, rotate, scale).
  - Linear and curvilinear surface measurements.
  - Direct volumetric measurements.

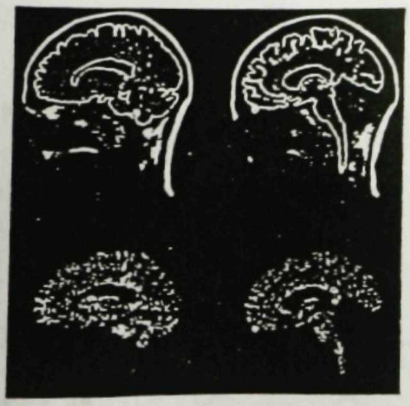


- Surface rendering for display of shaded surfaces from contours extracted from segmented image data.

IMAGE TRANSFORMATION

Images in the ANALYZE system may be modified through the following kinds of transformations:





- Linear combinations of images computed from user-specified formulas constructed with image file names as operands and mathematical, logical, and transcendental functions as operators.
- Spatial and frequency domain image processing including filters for smoothing, edge detection and contrast enhancement.
- Interactive graphic-based design of custom digital filters.
- Interactive manual object segmentation using thresholding, tracing and erasing.
- Semi-automated, interactive boundary detection for object segmentation.
- 3-D region growing for object segmentation.
- Automatic edge contour extraction.
- Fusion (integration) of images from different imaging modalities.

USER FRIENDLY INTERFACE

The ANALYZE user interface is a pop-down menu design with major options accessible on the top line of the screen. Selection of any option presents the user with an organized set of selections and entry fields relevant to the function desired. The user makes menu selections with the workstation's mouse and can use either the keyboard or mouse for field entries. The interface is logically organized to lead a user through the available options without difficulty. Context sensitive, on-line help is available.

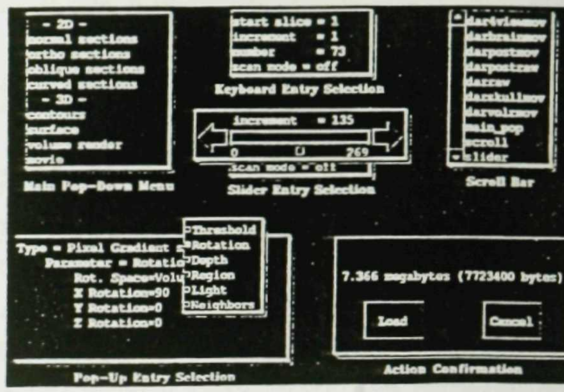


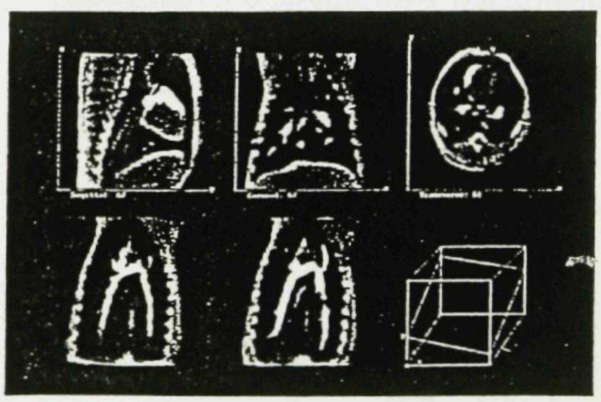
IMAGE DATA MANAGEMENT

The ANALYZE system contains facilities for retrieval and management of image data from a variety of sources. These image data management tools include:

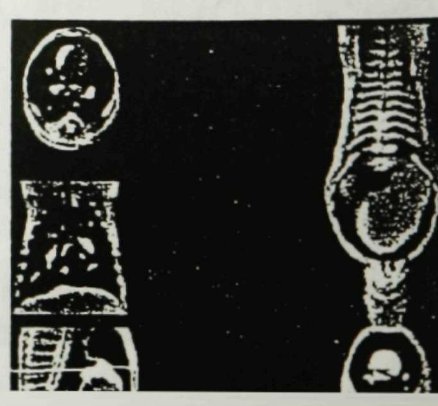
- Support for image information stored on 1/2" tape in several commercial scanner formats.
- Management tools for standard file operations such as delete, copy, rename, and archive to standard UNIX tar files on selected media (1/2" and 1/4" tape, 3 1/2" floppy).
- File display from disk for preview prior to loading data into workstation memory for further analysis.
- Image compression for reduced storage requirements.

2-D IMAGE DISPLAY AND REFORMATTING

The tools for interactive 2-D image display in the ANALYZE system include:



- Interactive display of multiple images with variable size control.
- Interactive mouse-driven intensity windowing.
- Rapid generation of orthogonal images from 3-D image volumes (transverse, coronal, sagittal).
- Display of 3-D volume image as a cube with control of size, intensity range, angle of view, and interactive dissections along orthogonal planes.



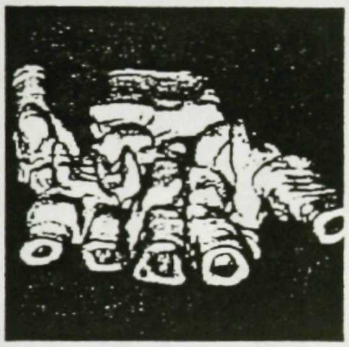
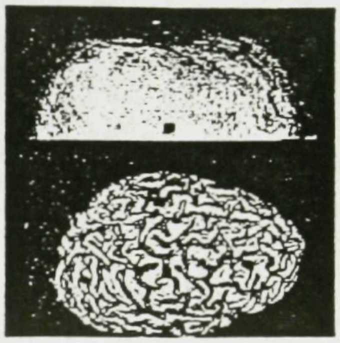
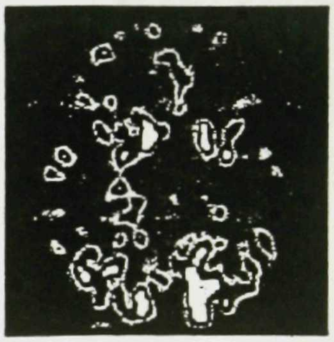
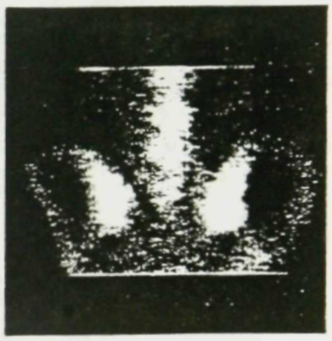
- Generation and display of arbitrary oblique planar images through 3-D volume images with interactive control of the orientation of the plane using conventional flying commands (e.g., pitch , roll, yaw).
- Generation of parallel oblique images for image volume reformatting along an arbitrary axis.
- Interactive generation of "curved" images and/or radial section images through regions traced on orthogonal images.
- Rapid display of images in cine movie loops with interactive control of speed and stop/start points.

CURRENT HARDWARE PLATFORMS

ANALYZE versions have been developed for the following workstation systems:

- Sun Microsystems Sun 3, 386i, 4, and SPARCstation.
- Silicon Graphics IRIS 4D Series and Personal IRIS systems.
- Hewlett Packard 9000/300 Series systems.
- Digital Equipment Corporation DECStation 5000 Series systems.
- International Business Machines RS/6000 Series and PS/2 systems.

The recommended configuration for these systems includes a color frame buffer and a minimum of 8 Mb of memory. The ANALYZE software system requires approximately 20 Mb of disk space. ANALYZE versions for other workstations are continually being developed.

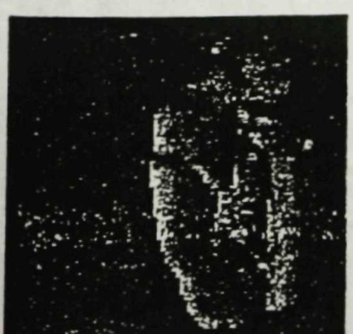
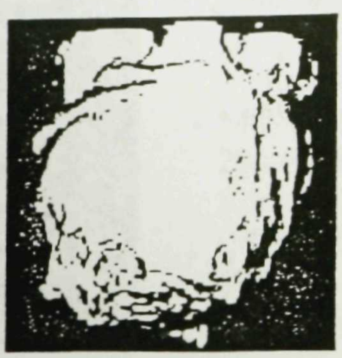
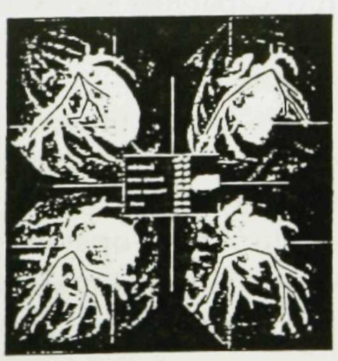
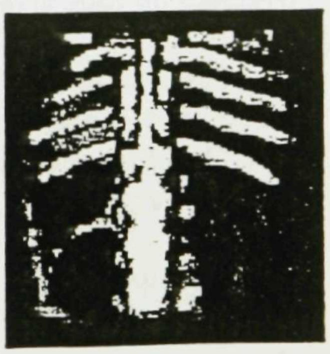





ANALYZE IMAGING APPLICATIONS

The ANALYZE system has been successfully applied to the display and analysis of the following imaging modalities:

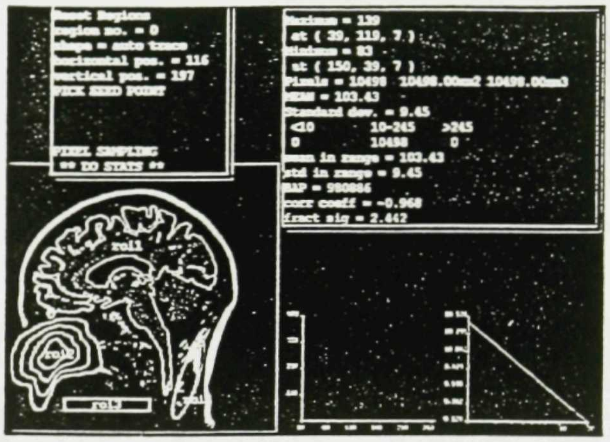
- X-ray Computed Tomography (CT).
- Magnetic Resonance Imaging (MRI).
- Positron Emission Tomography (PET).
- Emission Computed Tomography (SPECT, ECT).
- Ultrasound Imaging.
- Autoradiographic Imaging.
- 2-D and 3-D Microscopy (Confocal, Fluorescence, Electron, Light).

Other imaging modalities can be readily added to and supported by ANALYZE.

QUANTITATIVE IMAGE MENSURATION

The ANALYZE system contains several tools for the measurement of image features. These tools include:

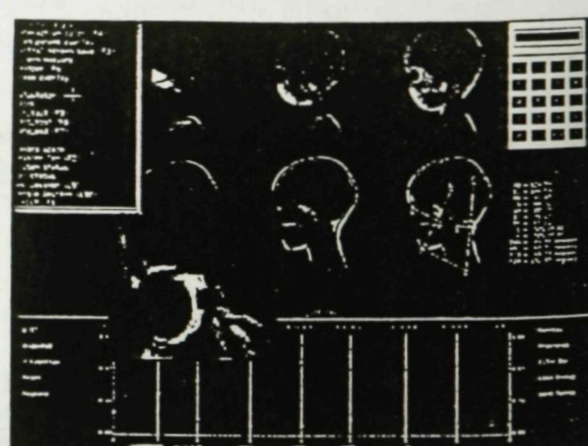


- Interactive plotting of line and trace profiles with linear measurement capabilities, including 3-D tracing.
- Interactive definition of multiple regions of interest using analytical shapes, arbitrary traces, or semi-automated boundary definition.
- Selection and automatic sampling of regions of interest with image parameters (e.g., extrema, means, standard deviations, density area products, fractal signatures) stored in data files.
- Interactive regional volume calculation.
- Regional shape and texture analyses.
- Output data file format selection for popular numerical analysis packages (S, SAS, RS/1, DIFF).
- Data plotting and statistical analysis.

ANCILLARY TOOLS / UTILITIES

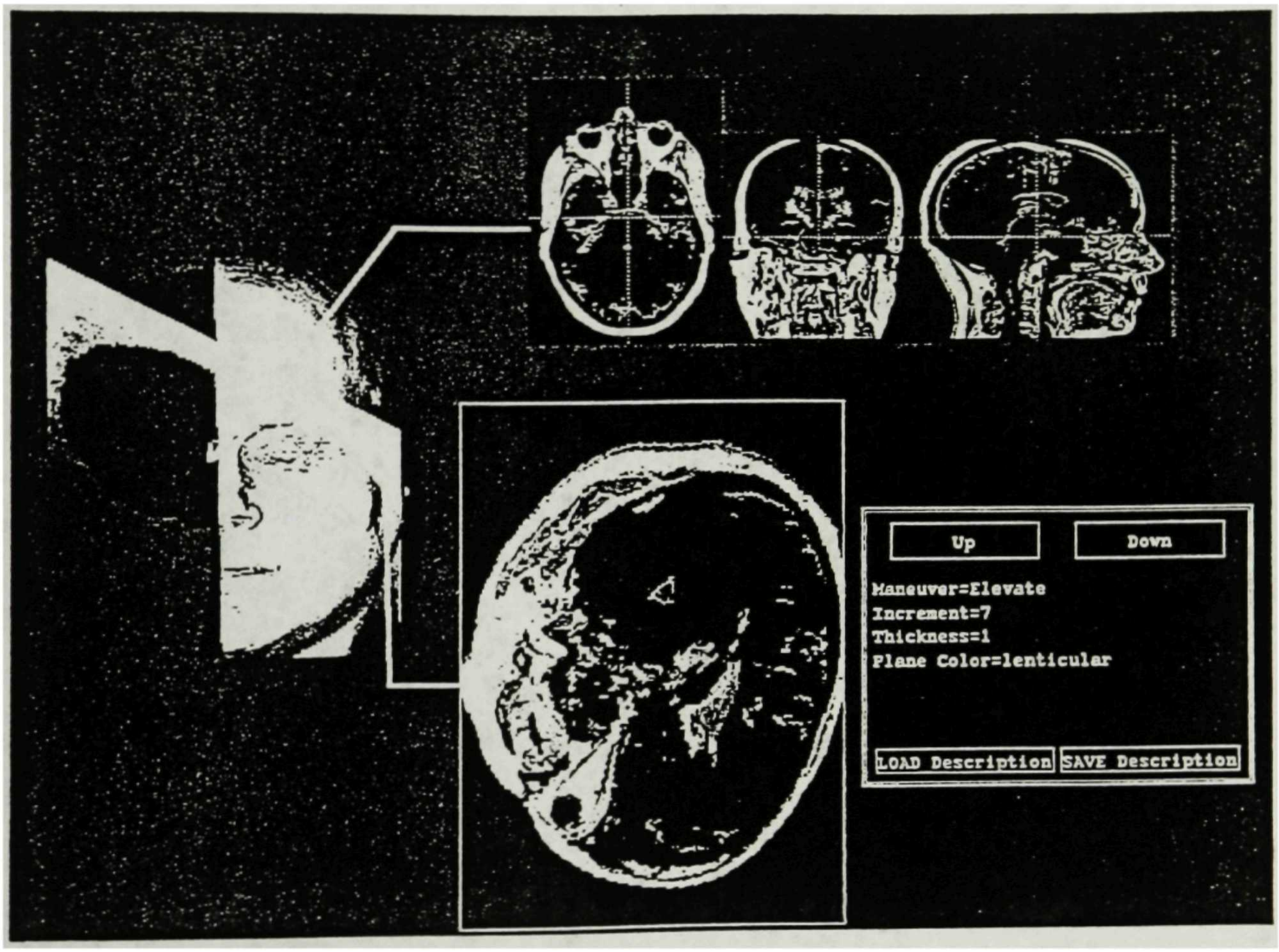
A rich suite of ancillary tools and utilities in the ANALYZE system include:

- Configuration of workstation environment, including main menu interface, font size, font style and color selection.
- Configuration for connection to networked peripherals, including tape drives and printers, and specification of numeric data output format.
- Screen editor with interactive options for cut, paste (with proportional scaling), overlays, text, labels, and graphics for full screen slide composition.
- Hardcopy output control for printing text and images.
- A macro facility for automatic recording and playback of display and analysis sessions.
- A magnifying glass for interactive magnification of areas of the screen at selectable sizes.
- Extensive interactive color manipulation.
- Screen region capture capability for saving to image files.
- Screen measurement tools.
- Editor for session notes, attachable to image files.
- On-line, context sensitive help documentation.
- On screen calculator and clock.
- Easy escape to and return from operating system.
- Multiple session start/resident/toggle for multiple image, multiple process analyses.



MAYO BIOTECHNOLOGY COMPUTER RESOURCE

The Mayo Biotechnology Computer Resource comprises a unique and technologically advanced facility for support of multimodality, multidimensional biomedical imaging investigations. It is associated with a comprehensive array of biomedical laboratories and patient clinical facilities within Mayo Clinic, and maintains a variety of extramural research collaborations. The Resource has a multidisciplinary professional and skilled technical staff who have an established record in pioneering imaging research and who are committed to development, evaluation and dissemination of new and improved technology, techniques and systems for scientific visualization and multidimensional biomedical image display and analysis.



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Mayo Foundation
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What's New in ANALYZE™ 5.1?

- Volume Rendering Tools - Object Compositing, True Transparency, Enhanced Multiple Object Manipulations, Dynamic Viewpoint Manipulation, Projection Integral Surface Rendering, Full 3D Editing, Animation Tools
- 2-D and 3-D Math Morphology Operations for Segmentation
- 2-D and 3-D Shape Measurement Tools
- 3-D Image Deconvolution Utilities
- Multi-Spectral Image Classification Tools
- 3-D Multimodality Image Registration and Fusion
- Generic 3-D Image Transformation Matrix Module
- 2-D and 3-D Image Transformation Compression Using Wavelets
- Addition of Several Enhancement Filters and Histogram Operations
- Multi-Panel Cine Movie Capability
- Optional Resizing (e.g. cubic) When Loading Images
- Additional Image Format Support (including ACR-NEMA)
- Enhanced Support for Multiple Storage Media Devices (1/2" tape, 1/4" tape in all densities, 8mm tape, 4mm DAT, R/W Optical)
- Color Postscript Support
- Support for Development of ANALYZE™ Program Extensions and Access to ANALYZE™ Shared Memory from External Programs
- X-Windows Version (Limited X-Windows Management, Full ANALYZE™ features)
- Supported Workstations (See backside for details)
- Several useful Ancillary Programs - Including Demonstator Script Program, TIFF-to-ANALYZE™ Convertor, and Transparency Image Maker
- All new User's Manual, Tutorial Notes and Demonstration Data

What's New in ANALYZE™ 6.2?

General Interface Improvements
- Snappier, more robust X-windows performance on all supported workstations
- Support for full 24-bit image display and manipulation
- Support for efficient color-dithering for 8-bit images
- Use of splines (including control handles) for tracing and drawing
- Selectable mouse button options for tracing/dragging
- Incorporation of user-specified calibration factors for image voxel value scaling
- Incorporation and display of user-specified units for voxel dimensions and values
- Display of image intuitive labels for spatial orientation of volume images/sections

Data Import/Export and Reformatting Enhancements
- New "Convert" program for file-to-file conversion of many image formats
- Offset data pointer for import of image data with headers
- Direct interpolation of multiple image volumes with varying dimensions into isotropic volume images (memory appending)
- Support for 8-bit and 24-bit Sun Rasterfile and TIFF formats
- Import/Export of oblique section orientations using matrix files
- Precise orthogonal plane selection using multiple reference lines with interactive definition of oblique planes

Volume Rendering Enhancements
- Improved region tracing, including new "paint" mode
- Voxel marking capability for anatomic reference in various display formats
- Improved manipulation of objects
- New surface tracking algorithm for improved surface area measurement
- Reset option in multiple object mode to return to original orientation

Image Transform Enhancements
- Improved 2-D and 3-D image compression using wavelet transforms
- Wavelet-based image noise reduction
- User defined 3-D kernels for spatial domain filtering
- Auto- and cross-correlation functions
- Image attenuation directly in Fourier domain by interactive selection of any region on spectrum display
- Maximum likelihood image deconvolution

Enhancements to Image Registration/Fusion by Surface Matching
- Improved registration algorithms
- Registration of multiple volume images simultaneously (i.e., 3 or more)
- Registration of reference points (from a list) to an image surface
- Sequential matching of 2-D slices through a volume stack
- Fusion and output of 24-bit color-overlayed images
- Interactive control of color fusion weighting factors
- Multipanel display of fused images

(over)

- Improvements to Multi-Spectral Classification
  - Multiple 2-D histograms for multiple spectra (configurable icons)
  - Magnification of selected spectral images for improved precision in region selection
  - Sketching mode for fast and precise region definition
  - Capabilities to save/load regions for sequential/repeated application of classifiers
  - Iterative relaxation algorithm for automated classifiers
  - Increased speed of automated classifiers
  - Calculation, display and saving of classified feature volume measurements

- Image Segmentation Enhancements
  - Direct import/export of object maps in segmentation modules
  - Display of "adjacent" (previous and next) images with current image being edited
  - Improved output of extracted contours (larger images and "ordered" contours)
  - Improved processes for use of math morphology (e.g., successive inclusion)

- Enhancements to Measurement Tools
  - Volume of Interest (VOI) support in Region of Interest program, including 3-D region definition and sampling using object maps
  - Improved sampling for parts of regions
  - Definition and simultaneous display of regions in associated image files while sampling
  - New stereological measurement algorithms for image volume, surface area, and curved line length

- Enhanced Demonstrator Program for X-Windows
  - Improved speed
  - Support for more screen transitions (fades, wipes, etc.)

- Support for Several New Workstation Models and Operating Systems
  - Sun SPARCstations running Solaris 2.X
  - MacIntosh Quadra workstation running AUX
  - DEC Alpha AXP workstation running OSF/1
  - Continuing support for all SGI systems (including new R4000 CPUs, Indigo, Indigo 2, etc.), IBM RS/6000, DECstation 5000, and HP Apollo 700 series workstations

- All New Documentation and Demonstration Data
  - Comprehensive User Reference Manual and Guide
  - Tutorials (Rendering, Segmentation, Registration, Multi-Spectral Analysis)
  - Tips 'N Techniques ("How to . . . " section)
  - Multi-modality 3-D image data sets of many biological/anatomic objects

ANALYZE™ 7.0 Enhancements

- **General Improvements**
  - Improved permission code management
  - Added support of permission code revalidation within ANALYZE™

- **Data Import/Export and Reformatting Enhancements**
  - Added support of "~" character in the Load Images program
  - Enhanced the image file offset pointer for import of image data with headers
  - Enhanced the capabilities for converting foreign file formats
  - Added 24-bit TIFF output file support
  - Added support for DICOM 3

- **Volume Rendering Enhancements**
  - Added new surface area measurement algorithm to the AREA Measure Tool
  - Added a Moved Objects Interaction Warning message
  - Improved the CHANGE VIEW Renderings
  - Added Radial Rendering Preview

- **Image Transformation Enhancements**
  - Added absolute value function support
  - Added four new biorthogonal wavelets

- **Image Segmentation Enhancements**
  - Added enhancments to the multiple object mode
  - Added open trace support
  - Enhanced limit management
  - Added force selection of region definition
  - Changed defaults for Auto Traces

- **Enhancements to Multi-Spectral Classifications**
  - Added a post-processing mode filter
  - Enhanced Auto Trace region definition

- **Improvements to Surface Matching**
  - Added an option to step-through displayed images in 3 panel display mode

- **Enhancements to Region of Interest**
  - Added automatic centering of region on local average max or min
  - Added interactive reporting of max or min values within regions
  - Added option to toggle the display of defined regions
  - Added optional under-the-line sampling
  - Added VOI store/modify mode toggle
  - Added the option to store histograms in any of the supported .stats file formats

- **Enhancements to Stereology**
  - Added Surface area estimation

ANALYZE™ 7.5 Enhancements

- **New Program: Tree Analysis**

  - Automated morphological detection and generation of branching 'tree' traces.
  - Integrated display of traces with images using MIP projection images.
  - Direct display and visualization of individual segment positions and branch node points.
  - Interactive selection of segments with generation and display of perpendicular obliques.
  - Support for output of oblique images along entire length of trace or a specific segment.
  - Brightness Area Product (BAP) computation and output along trace.
  - Trace files in ASCII text, including relationship to other points and segment length statistics.
  - Useful for volume images containing vascular structures, i.e., MRA, CT with contrast studies.

- **Data Import/Export and Reformatting Enhancements**

  - Support added for DICOM 3, Siemens/CTI PET, and SMIS MRI image format conversion.
  - Support for reading GE Advantage 4mm DAT tapes.
  - Implemented bi-directional conversion between 8-bit images and object maps.
  - Resizing via nearest neighbor selection added to volume loading.

- **Volume Rendering Enhancements**

  - Direct surface rendering of objects in object map (without need for voxel gradients).
  - Cut surface rendering options allow variable rendering types along cut.
  - Surface projection enhancement to skip voxels along path permitting interior surface rendering.
  - Section viewing option to show only image voxels from currently visible objects.
  - Depth information along ray path shown for interior voxel selection in Ortho Sections.
  - Oblique sections enhancement to show sections orthogonal to current oblique.
  - Fly buttons can be removed from display in lieu of using keyboard commands.
  - Region growing connect procedures include 18- and 26-connected search algorithms.
  - Volume advance key added to allow direct selection of specific volume from multi-volume data.

- **Image Transformation Enhancements**

  - Oblique sections enhancement to generate perpendicular obliques along a curve.
  - Fly command available as mouse selections in regions of the oblique image.
  - Transformation via matrix application can be done using volume image in memory.
  - True 3-D median filter added to the Spatial Filter program.

- **Image Segmentation Enhancements**

  - Thinning routines in 3-D Morphology updated to properly handle ends of branching structures.
  - Improved, more efficient connect routines implemented (not longer uses stack file on disk).
  - Sequential labelling of connected objects in order of decreasing size.
  - Direct saving of morphologic processed volume images added to 3-D Morphology.
  - Additional function to generate branching 'tree' traces in support of new Tree Analysis program.
  - Saved traces from spline contours also include the spline control points.
  - Added display sizes smaller than actual size to support editing of very large images.
  - Improved display modes for multiple object editing.

ANALYZE™ 7.5 Enhancements

- **Enhancements to Multi-Spectral Classification**

  - Algorithms implemented for unsupervised classification.
  - Anisotropic diffusion added as an optional pre-processing step prior to classification.
  - Principal component analysis enhancement for reduced dimensionality visualization.
  - Mode filter implemented for post-processing smoothing of classes.
  - Direct support for 24-bit RGB images as multispectral bands implemented.
  - User-definable default class colors added.

- **Image Measurement Enhancements**

  - Improved mechanisms for sampling multiple line profiles through a sequence of images.
  - Output of statistics summaries from the Plot program supported.

- **Enhancements to Region Of Interest (New ROI Program)**

  - Multi-volume application of VOI sampling supported.
  - Improved definition and sampling of several ROI shapes, including ellipses.
  - Enhanced ROI trace definition via editing function for portions of defined traces.
  - Improved viewing of interactive trace drawing via different colored traces.
  - Automatic sampling of all objects during analysis using object maps.
  - Added feature for sampling under region boundary pixels using partial pixel assignment.
  - Improved approach to summing statistics for multiple regions through a sequence of images.
  - Multiplicative user-defined scale factor added for scaling value-based output statistics.
  - User-adjustable floating point precision for image value-based displays and output.
  - Enhanced display modes for objects on images in multiple object sampling mode.
  - Added support for non-closed traces, including spline control.

- **Enhancements to Stereology**

  - Improved coefficient of error calculation for volume estimation.
  - Automated sampling of pre-segmented structures.

- **Miscellaneous Improvements**

  - Improved support for hardcopy output through standard UNIX command pipes.
  - User programs accessible through menu items can now cause ANALYZE™ removal from screen.
  - Screen Edit cut/paste buffer can be flipped vertically or horizontally using keyboard options.
  - New feature allows invocation of ANALYZE™ with pre-loaded image memory segments.

Software for Volume Visualization or 3-D Reconstruction

Appendix D

Software

This is a list of software (both commercial and otherwise) available for 3D reconstruction of MRI, CT, confocal, and serial-section data for medical/life-sciences imaging.

3-D-E

Windows-based contour editor and visualizer from Data Cell Ltd. *(Platforms: PC; Cost: ~$1500)*

3DVIEWNIX

3DVIEWNIX is a transportable, very inexpensive software system developed by the Medical Image Processing Group, Department of Radiology, University of Pennsylvania, Philadelphia. It has state-of-the-art capabilities for visualizing, manipulating, and analyzing multidimensional, multimodality image information. It is designed to run on Unix machines under X-windows. *(Platforms: SGI, Sun, PC; Cost: unknown)*

Analyze

Provides an environment for the interactive visualisation and manipulation of 2-D, 3-D and 4-D biomedical images. An integrated set of tools is provided to allow data to be interrogated in both two and three dimensions. *(Platforms: SGI, Sun, HP, DEC; Cost: $$$)*

AutoDeblur

AutoDeblur performs blind deconvolution for 3d data. *(Platforms: SGI; Cost: unknown)*

AVS

AVS - commercial visualization package from Advanced Visual Systems, Inc. *(Platforms: SGI, Sun, HP, DEC; Cost: unknown)*

Oncor

Biomedical image measurement and analysis system. *(Platforms: Mac, PC; Cost: $$)*

Bioquant

3D reconstruction and quantitative histochemistry system. *(Platforms: PC; Cost: unknown)*

BOB (GVLware)

The Army High Performance Computing Research Center (AHPCRC) has been developing a set of tools to work with large time dependent 2D and 3D data sets. *(Platforms: SGI; Cost: free)*

C_Images 3D

3D Image analysis package by Foster-Findlay Associates (UK). *(Platforms: PC (DOS, Windows), Unix (IBM, Sun, SGI); Cost: unknown)*

CT

CT programs by Malcolm Slaney. *(Platforms: Many; Cost: free)*

Deltavision

Image acquisition and deconvolution software for 5-dimensional microscopy. *(Platforms: SGI; Cost: unknown)*

Dicer

Slicer/Dicer is a volumetric visual data analysis package. *(Platforms: Mac; Cost: $)*

DIP Station

Macintosh-based reconstruction package. *(Platforms: Mac; Cost: unknown)*

Dr. Razz

CT/MR display and analysis program for Macintosh color computers. *(Platforms: Mac; Cost: free)*

EutecticSSRS

Low-end 3D reconstruction, mapping, and analysis system. Contour-based using a digitizing tablet. *(Platforms: PC; Cost: $24-28k (NTS), $8-10k (NTSV))*

FAST

It is a software environment for visualizing and analyzing Computational Fluid Dynamics data. *(Platforms: SGI; Cost: free)*

HVEM 3D

PC-based serial section reconstruction program for microscopy created by Kinnamon/Young at UColorado. *(Platforms: PC; Cost: unknown)*

IAP

Imaging Applications Platform is a commercial package for medical and scientific visualization. *(Platforms: Most workstations; Cost: $$)*

IBM Data Explorer

IBM Data Explorer. *(Platforms: IBM, SGI, Sun, HP, DG; Cost: unknown)*

IDL

IDL (Interactive Data Language) is a package for the interactive reduction, analysis, and visualization of scientific data and images. *(Platforms: IBM, SGI, Sun, HP, DEC, PC, Mac; Cost: $$)*

Image Pro

Image Pro from Media Cybernetics ($2,999). *(Platforms: PC (Win3.1, NT, 95); Cost: $$$)*

ImageSpace

Software environment for confocal imaging. *(Platforms: SGI; Cost: unknown)*

Image Volumes

Interactive image processing, contour editing, 3D reconstruction for confocal, EM, X-ray tomography, and MRI. *(Platforms: SGI; Cost: unknown)*

Imagist

Imagist2 from Princeton Gamma Tech- integrated microscope and analysis systems. *(Platforms: Sun; Cost: unknown)*

IMOD

Image modeling package used for EM tomography and serial section reconstruction. *(Platforms: unknown; Cost: unknown)*

IRAF

IRAF (Image Reduction and Analysis Facility). *(Platforms: unknown; Cost: unknown)*

KBVision

Software environment for creating image understanding applications. *(Platforms: Sun, IBM, DEC, SGI; Cost: $$)*

Khoros

Very large, general image processing toolkit. *(Platforms: Sun, SGI, IBM, DEC, HP; Cost: free)*

MacCubeView

Designed to display a texture map image of three-dimensional (3-D) data. *(Platforms: Mac; Cost:*

shareware)

MacPhase

2D data analysis and visualization application for the Macintosh. *(Platforms: Mac; Cost: unknown)*

MacStereology

MacStereology is package designed to make measurements of images and to make 3-D reconstructions. *(Platforms: Mac; Cost: unknown)*

MCID

Image analysis and qunatification mainly for fluorescence imaging. *(Platforms: PC; Cost: unknown)*

MetaMorph

Integrated microscope image capture, enhancement, reconstruction, and visualization system. *(Platforms: PC; Cost: unknown)*

MicroMorph

MicroMorph is the software aid in learning the mathematical morphology techniques of image analysis. *(Platforms: PC; Cost: Varies)*

MicroVision II

MicroVision II can be used for for visualising point-sampled data volumes. produced by 3D scanning devices such as MRI, PET, CT-scanners and confocal microscopes. *(Platforms: PC; Cost: unknown)*

MicroVoxel

MicroVoxel is a 3D imaging package that imports data from BioRad MRC-600 files, TIFF files, or raw 8-bit data. *(Platforms: PC; Cost: unknown)*

Montage

Montage is one of the first complete serial-section reconstruction packages and was produced at the University of Pennsylvania. *(Platforms: Sun, SGI, IBM, PC; Cost: free)*

Mvox

Mvox is a general purpose tool for visualization and manipulation of a wide range of 2-4D grey level colour images and 3D surface graphics. *(Platforms: SGI, HP, IBM; Cost: $$)*

NCSA Tool Suite (DataSlice, Viewit, Tiller)

3D Visualization tools from the NCSA. *(Platforms: Sun, SGI, DEC, IBM, Cray, Mac; Cost: free)*

Neuro_Echo, Neuro_SPGR, Neuro_Lobe

Neuro_Echo aids analysis of double-echo MR brain scans from the GE Signa imager. The program uses axial scans to segment the brain scans into gray matter, white matter and CSF. *(Platforms: Sun; Cost: unknown)*

Neurolucida

Low-end interactive image analysis software for neuron tracing and anatomical mapping. *(Platforms: PC; Cost: unknown)*

NIH Image

NIH Image has painting and image manipulation tools, a macro language, tools for measuring areas, distances and angles, and for counting things. *(Platforms: Mac; Cost: free)*

Nuages

This is Bernhard Geiger's (INRIA) reconstruction package. *(Platforms: Sun, SGI, DEC; Cost: free)*

OLPARS

On-Line Pattern Analysis and Recognition System from the PAR Government Systems Corporation. *(Platforms: Sun, DEC; Cost: unknown)*

Pixar

High-end visualization and rendering for movies, but also for the medical community. *(Platforms: SGI; Cost: $$$)*

Pixcell

Pixcell from Sandia Labs. *(Platforms: Sun; Cost: free)*

PV-Wave

PV-WAVE from Visual Numerics. *(Platforms: unknown; Cost: unknown)*

RMN

A Nuclear Magnetic Resonance (NMR) data processing program for the Macintosh. *(Platforms: Mac; Cost: unknown)*

Reconstruction Of Serial Sections (ROSS)

Serial-section based reconstruction and visualization system for microscopy. *(Platforms: SGI; Cost: free)*

SciAn

Florida State University scientific visualization package. *(Platforms: SGI, IBM; Cost: free)*

Semper6

General image Processing and acquisition system. *(Platforms: PC, DEC, Sun; Cost: unknown)*

SGI Explorer

SGI Iris Explorer. *(Platforms: SGI, Cray, DEC, HP, IBM, Sun; Cost: unknown)*

Sunview

Sunview - available from SunSoft. *(Platforms: Sun; Cost: unknown)*

SunVision

Sun Visualization software, providing SunIPLib (Image Processing), SunVoxel (volume rendering), SunART (high-quality rendering), SunGV (interactive 3D graphics). *(Platforms: Sun; Cost: unknown)*

Synu

UCSD reconstruction/visualization program. *(Platforms: SGI; Cost: free)*

The Explorer

Macintosh-based package from UCLA. *(Platforms: Mac; Cost: free)*

TIM

Tomographic Imaging- PC Software for 3D image processing of pixel planes. *(Platforms: PC; Cost: unknown)*

Theraview

No information available. *(Platforms: unknown; Cost: unknown)*

V

Public-domain software package for magnetic resonance imaging and spectroscopy data. *(Platforms: Unix; Cost: free)*

Vida

Commercial volumetric display and analysis tool for Unix. *(Platforms: Sun, HP, SGI; Cost: $$$)*

View

SGI-based program from UNC. *(Platforms: SGI; Cost: unknown)*

Vis5D

Visualization program for time-varying multi-variate 3-D gridded data. *(Platforms: SGI, IBM, Sun, HP, DEC; Cost: unknown)*

VisAD

Visualization program for interactively steering and visualizing scientific computation. *(Platforms: SGI; Cost: unknown)*

VolPack

VolPack is a portable software library for volume rendering. *(Platforms: SGI, Sun, HP, DEC; Cost: unknown)*

VolVis

Volume Visualization package from SUNY. *(Platforms: SGI, Sun, HP; Cost: unknown)*

Vox-L

MR and CT visualizer. *(Platforms: unknown; Cost: unknown)*

Voxblast

Voxel-based 3d volume rendering system developed by Randall Frank at the University of Iowa Image Analysis Facility. *(Platforms: SGI, Sun, DEC, HP, IBM, Mac, PC; Cost: unknown)*

VoxelBox

3D Volume renderer for Windows. *(Platforms: PC; Cost: $)*

VoxelMan 3D

Interactive atlas of skull and brain. *(Platforms: unknown; Cost: unknown)*

VoxelView

VoxelView software from Vital images for 3D reconstruction of images. *(Platforms: SGI, Mac; Cost: unknown)*

Voxtool

Voxtool from General Electric. *(Platforms: PC, Unix; Cost: unknown)*

VROOM

VROOM (Vol. Rendering by Object Oriented Meth.). C++ Library. *(Platforms: unknown; Cost: unknown)*

Wavefront

Wavefront Data Visualizer. *(Platforms: SGI, Sun, IBM, HP, DEC; Cost: unknown)*

WHIP

General purpose image processing software from GW Hannaway & Associates. *(Platforms: SGI; Cost: unknown)*

XCOSM

X-Windows interface to Computational Optical Sectioning Microscopy. *(Platforms: SGI, DEC, Sun; Cost: Free)*

Zmode

Software/hardware that can convert a series of parallel MRI/CT scan images to a 3D reconstructive model in a CAD system. *(Platforms: unknown; Cost: unknown)*

Back to 3D Reconstruction home page

Procedures for Downloading VH Images from NIH (Macintosh)

Appendix E

Downloading Images from the Visible Human Project (VHP) Dataset

MACINTOSH

Software Used:

Fetch 3.0.1

- Available in the LRC under the icon **LRC Remote** → Patron folder → Public Software → Internet/TCP/IP → FTP and Archie → Fetch 3.0.1 Installer

MacCompress3.2

- Available for download from VHP account.

Adobe Photoshop

- Available on LRC MACs.

Procedure:

Open Fetch 3.0.1 application. You will see a box asking for the following:

Host	
User ID	
Password	

Host = vhnet.nlm.nih.gov

<u>For Visible Female</u> -

User ID = vhpfemale
Password = vis!female

<u>For Visible Male</u> -

User ID = vhpmale
Password = vis!male

After clicking on OK, this will put you into the VHP directory looking something like

```
.
..
Female
Male
bin
utils
```

If this is your first time accessing the images or you do not have MacCompress3.2 accessible, double click on Utils. Single click on MacCompress3.2.

<u>IMPORTANT</u>:

Before you download any files with Fetch, it is vital to check the following to ensure viable data or images:

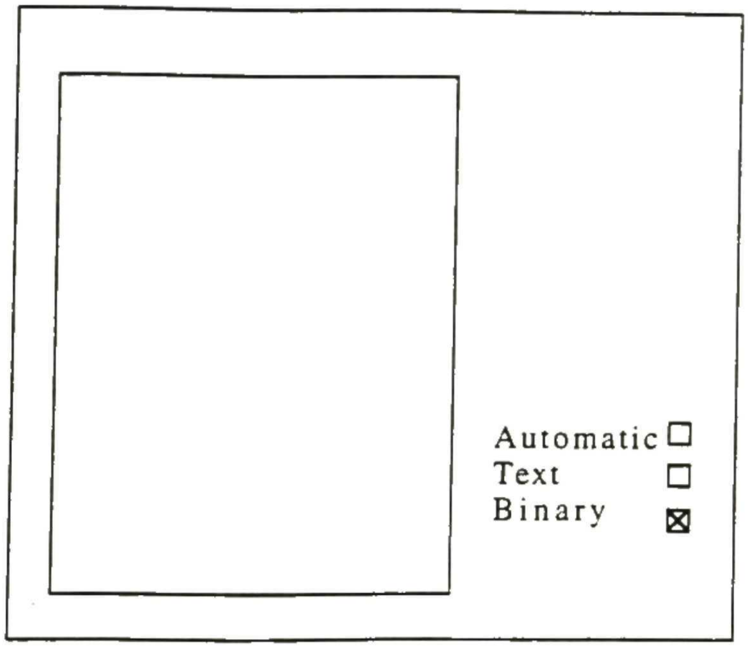
The top of the screen will look like this when you are in Fetch:

```
File   Edit   Remote   Directories   Customize   Windows
```

Under Customize, select Preferences. Then click on download and ensure the "Automatic" defaults to "Text" box is not selected. Click on OK.

Then, still under Preferences, click on Formats and ensure that none of the boxes for **Recognize and Decode** are NOT SELECTED. Click on OK.

Also make sure Binary is selected in the lower right hand corner of the main screen in Fetch.



After you have selected MacCompress3.2, press Get File to download it. Select where you want the file to be saved.

After you have downloaded MacCompress, return to the main directory by clicking Utils and selecting the /.

Depending on whether you chose the Male or Female account, click on the appropriate folder

You should see something like this:

.
..
Full Body
Full Color
Radiological
24bit
Index

For full color cadaver images select Full Color. For CTs or MRIs select Radiological. You should see a directory like this after selecting Full Color :

Head
Thorax
Abdomen
Pelvis
Legs

Choose your selection. For cadaver images, the directory should have files named avffile#.raw.Z with file sizes approximately 4.5 Mb.

Single click on your selected file and click on Get File. Select the appropriate destination and click Save.

To repeat downloads, select another file and follow download procedure.

After closing Fetch, find the appropriate downloaded, compressed file. For example, a cadaver image file named as avffile#.raw.Z.

To decompress this file, click on the file icon then click OK to verify decompression of the startupfile (the compressed cadaver image). Alternatively, open MacCompress3.2 then under File select Open.

After decompression, the file name should be the same with the exception of the removal of the suffix .Z

avffile#.raw would be the name of the previously mentioned cadaver image file.

Open Photoshop and select your image to be opened. Under the Raw format, the image dimensions should be entered.

For an Anatomy image:

Width	2048	Pixels
Height	1216	Pixels
Channels	3	
	☐	Interleaved
Header	0	Bytes
		OK

To repeat downloads, select another file and follow download procedure.

After closing Fetch, find the appropriate downloaded, compressed file. For example, a cadaver image file named as avffile#.raw.Z.

To decompress this file, click on the file icon then click OK to verify decompression of the startupfile (the compressed cadaver image). Alternatively, open MacCompress3.2 then under File select Open.

After decompression, the file name should be the same with the exception of the removal of the suffix .Z

avffile#.raw would be the name of the previously mentioned cadaver image file.

Open Photoshop and select your image to be opened. Under the Raw format, the image dimensions should be entered.

For an Anatomy image:

Width	2016	Pixels
Height	1248	Pixels
Channels	3	
	☐ Interleaved	
Header	0	Bytes
	OK	

Using the Photoshop RAW image format:

	Anatomy	CT	MRI
Width (Pixels)	2048	512	256
Height (Pixels)	1216	512	256
Channels	3	2	2
Interleaved		X	X
Header (Bytes)	0	3416	7900

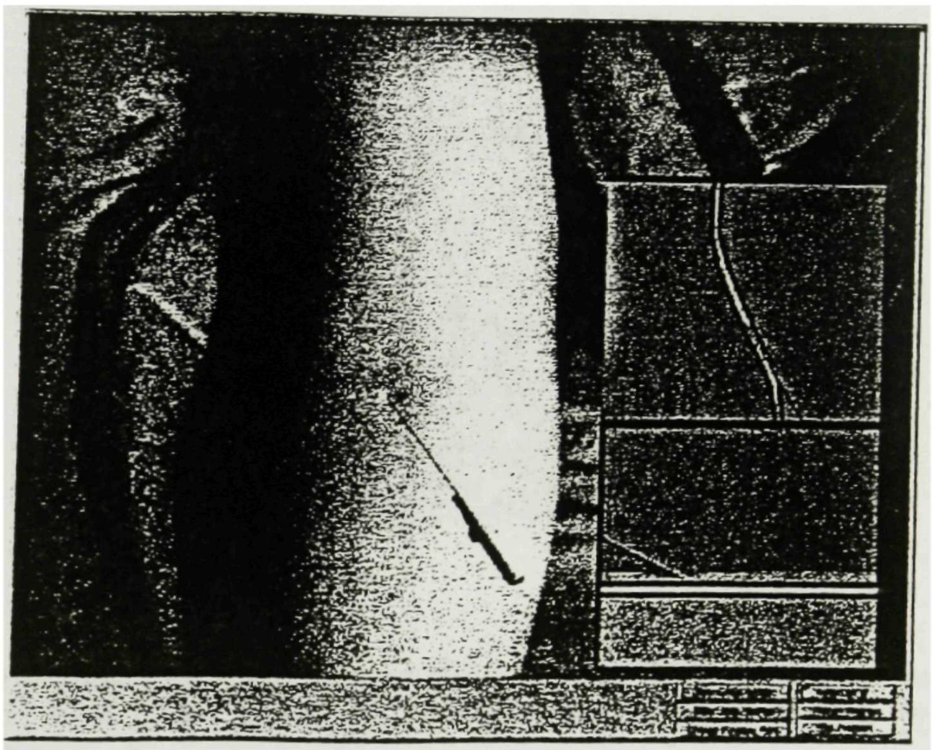
After clicking OK, photoshop will display the color anatomy images but the CTs and MRIs will appear black. To view CTs or MRIs, set the Mode (on the photoshop menu bar at the top of the screen) to Greyscale. Then, under Image on the menu bar, select Adjust and click on Auto. The CTs and MRIs will be visible.

High Techsplanations Inc. Simulations

Appendix F

SIMULATIONS

Intravenous needle insertion

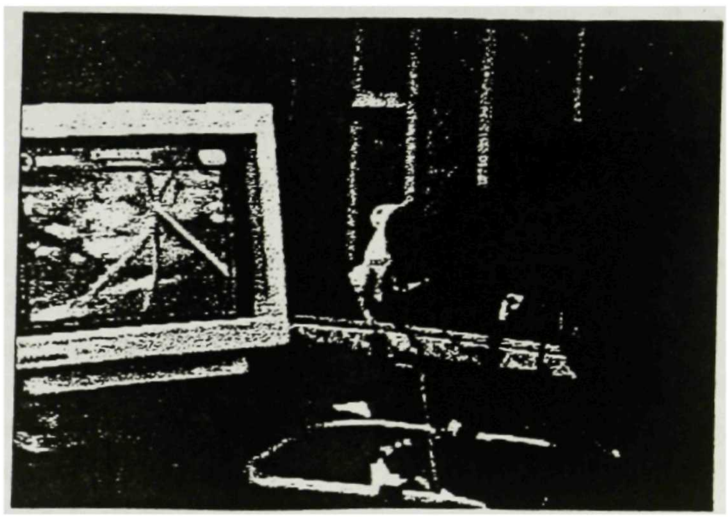


The Plattsburgh Procedural Simulator for Nursing Education (PPSNE), Module #1, was developed jointly between HT and the State University of New York at Plattsburgh. The intravenous infusion simulator was developed for nursing students and other health personnel to practice venipuncture. This is the first virtual reality application that is used for on-site training of medical personnel.

The PPSNE IV simulator utilizes a force feedback input device developed specifically for this application by Immersion Corporation. Using the virtual cannula, the trainee is able to sense the tactile response of needle placement, from the "pop" as the needle enters the skin, through the entry into the vein. The simulator provides six different cases that offer varying levels of real-world difficulty and complications. The simulator can guide the trainee through the decision making process, and offers motion playback for self assessment or evaluation by an instructor.

SIMULATIONS . . .

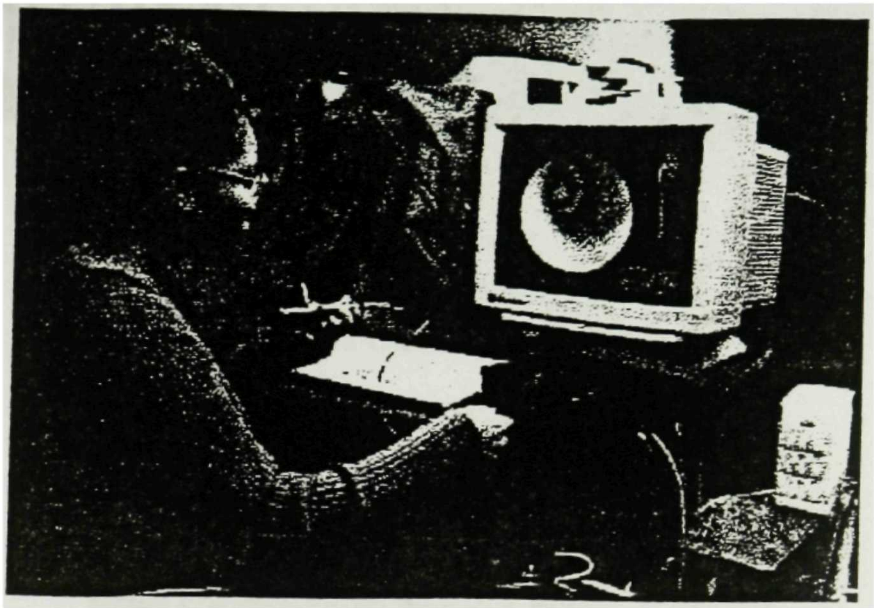
Virtual laparoscopy



A prototype laparoscopic surgical simulator software was developed for demonstration at the American Urologic Association meeting in 1994, and was underwritten by Merck & Co., Inc. The simulation allowed physicians to perform a lymph node dissection procedure, permitting grasping, movement and cutting of deformable vessels. Modeling of soft-tissues was physics-based, so the end-user could stretch and deform tissues and the tissues responded with elastic properties.

The software took advantage of the Silicon Graphics, Inc. (SGI) Reality Engine in both the extensive polygon count and the use of texture mapping on the surfaces of the organs. In an early version of the program, an arbitrary clipping plane was implemented to allow the end-user to 'cut' through the abdomen and to reveal underlying tissues. A special capping algorithm was implemented to render solid tissues (so that these tissues did not appear as hollow surfaces). Additional capabilities were added to allow real-time manipulation of the physically-based deformable soft tissue structures with a set of instrumented laparoscopic tools.

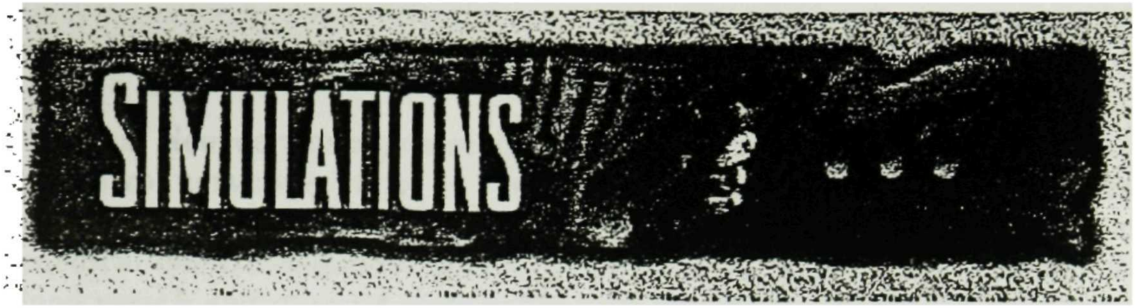
Flexible ureteroscopy



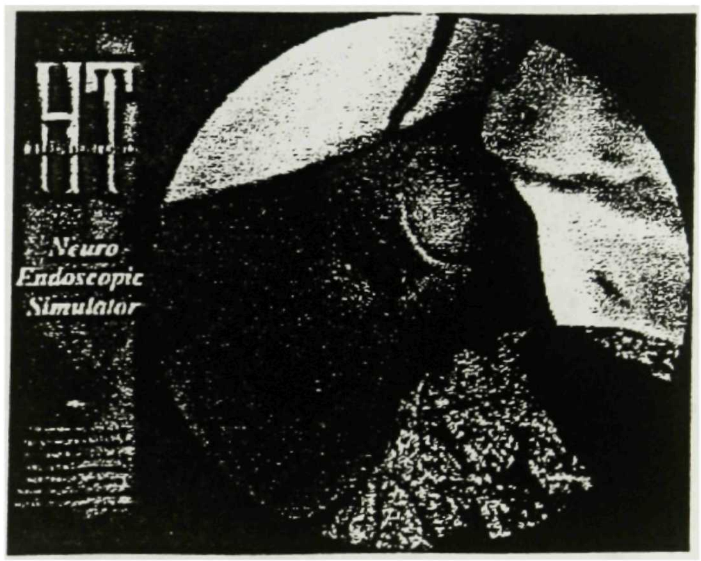
Flexible ureteroscopy is a minimally invasive endoscopic technique where a small caliber, flexible fiber optic endoscope is passed through the urinary tract to inspect both the ureter and the intra-renal collecting system. This represents an ideal simulation of an endoscopic procedure, because movement within the urinary tract is limited and there are only slight variations in the orientational position of the endoscope during its travel through the urinary tract. Also, the amount of tactile feedback during the actual procedure is very limited, lessening the need for force feedback during the simulation.

The flexible utereoscopic simulation developed by HT was funded by Karl Storz Endoscopy America, Inc. The first step in the design of the simulator was to define the graphics and the input-device required for the flexible ureteroscopy procedure. Both multiple-point collection detection and culling were implemented as part of the software. Culling was important to maintain interactive frame rates during the simulation. Surfaces of plastic anatomical models were digitized and formatted to provide the virtual anatomy.

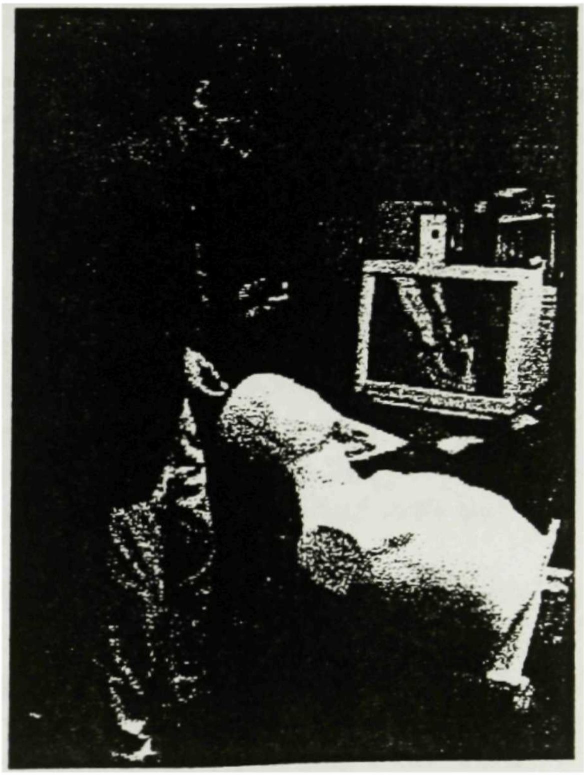
An input device was designed and implemented for HT by ______ (Mountain View, CA) using an actual flexible ureteroscope supplied by Karl Storz Endoscopy America. These instruments were equipped with appropriate electronics required for proper tracking of the instruments' position during manipulation. The simulation included a kidney stone, a small tumor and a normal air-bubble, that could be positioned in various locations within the intra-renal collecting system. Timers were also built into the software to allow assessment of the amount of time that the user required to navigate up the ureter and through the inside of the kidney. For more information on this simulator, please refer to Preminger et al. 1996.



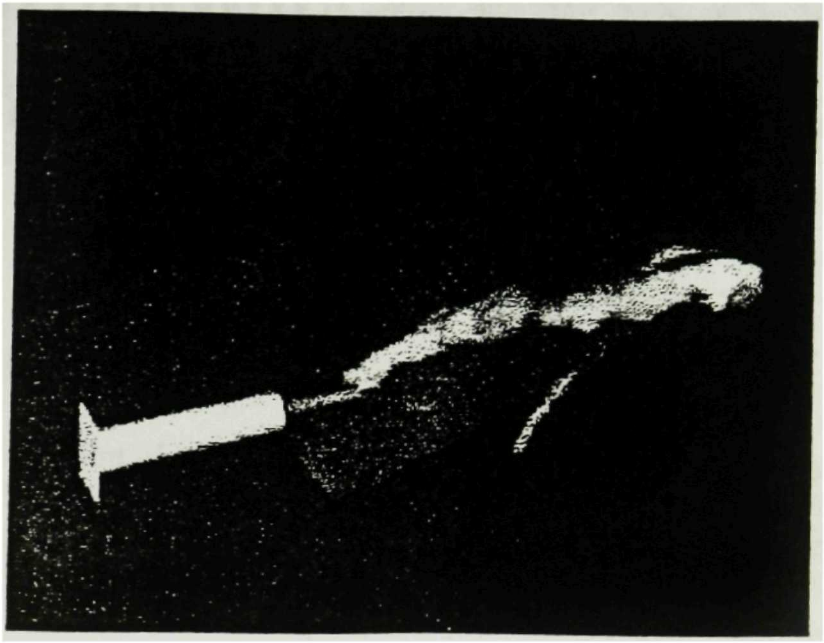
Neuroendoscopy



The 'Rowe' Virtual Neuroendoscopy simulator was designed for exploration of the ventricular system of the central nervous system, and was funded by Johnson & Johnson Professional - Codman. A cast of the third and lateral ventricles was digitized to provide the geometric model, and medical illustrations provided the texture maps for the lining of the ventricles including blood vessels and choroid plexus. The user is able to navigate throughout the ventricles using an endoscopic device threaded through the top of a mannequin. This simulator was developed in collaboration with Dr. Richard Rowe, a neurosurgeon at the National Naval Medical Center in Bethesda, MD, The next figure shows the use of the virtual neuroendoscopy simulator.



Subclavian line placement



A simulator for training military personnel in how to place a central venous line into the subclavian vein was funded by the U.S. Navy. The procedure involves placement of a needle-tipped catheter into the central venous system, a procedure that is often performed in trauma situations where administration of large volumes of fluids is required. The hypodermic syringe, which is first introduced into the vein, is simulated by a PHANToM device (SensABLE Devives, Cambridge, MA) synchronized with the virtual syringe in the simulation.

Anatomical modeling of the surgical field involved creation of a 3D model of the upper thorax extracted from the Visible Human 2D photographic data set. The site of entry of the catheter was simulated using a photographis texture map of the upper chest wrapped around the 3D model. The procedure involves puncturing of the skin, which means that the surface must deform with appropriate resistance using the force-feedback device. The syringe is then advanced along the clavicle, and the operator must use the feel of traveling down the bone to locate the appropriate vein to puncture. This again involves appropriate tactile feedback, this time mimicking movement of the needle against the bone. Finally the vein is deformed, and then punctured with a 'pop', and the user sees pulsating blood in the syringe.

Heart catheterization

A tradeshow demonstration of coronary angioplasty was underwritten by Marion Merrell Dow (now Hoescht-Marion-Rousell). The application was configured to run on an SGI Indigo2 Extreme, which was capable of rendering the structure of the vasculature in adequate detail for depicting the coronary anatomy.

The application was configured to maintain real-time frame rates of greater than 15 frames per second, and support tracking of a catheter-like input device that exhibited appropriate tactile feedback. The feedback included providing the user with greater resistance when the catheter entered regions of the artery clogged with artherosclerotic deposits.

Interventional Radiology

The 'Dawson-Kaufman' Interventional Radiology simulator was designed to allow physicians to practice angioplasty and other techniques for opening blocked arteries in a setting that duplicates the look and feel of a real procedure. The simulation is based on real patient cases and uses a video monitor that duplicates the black-and-white x-ray pictures that interventional radiologists actually watch on a fluoroscopic screen. Fluid dynamics supports realistic events such as dye diffusion. The simulation also incorporates tactile feedback so that physicians manipulating guide wires and catheters "feel" sensations actually experienced during procedures, such as encountering an unexpected obstruction in an artery. The computerized simulator also makes users suffer the consequences of their mistakes.

Some of the specific features of the simulator include:

- Users practice several patient case scenarios for treating a blocked iliac artery, a blood vessel in the pelvis that, if clogged can cut off blood flow to the lower extremities. In the procedure, physicians enter the vascular system through a puncture in the femoral artery in the groin and thread tiny instruments through the vascular system to the blocked artery.
- Physicians can manipulate three devices common to many interventional procedures: guide wires, sheaths (tubes through which interventional radiology instruments are passed) and catheters. The computer tracks all three devices independently, simulates the "feel" of each device as it encounters various conditions inside the blood vessels and reacts with an appropriate "complication" if the wrong device is selected for a procedure.
- The simulation allows for a variety of treatment options, depending on the individual case. For example, physicians can inject contrast agents, or dyes, to take an angiogram (x-ray picture) of the blood vessels. Or, they can treat a blockage with angioplasty (opening of clogged arteries with balloon catheters) or by administering clot-busting drugs via catheters.
- The computer will simulate a number of complications that may be encountered in a procedure, such as encountering atherosclerotic plaque in the blood vessels leading to the iliac artery - a common complication in older patients; the puncture of a blood vessel with a guide wire ; rupture of an angioplasty balloon; or a perforated blood vessel.

The simulator was developed as a joint effort between HT and Massachusetts General Hospital, involving Dr. Steven Dawson, Interventional Radiologist and Associate Director of the Center for Innovative Minimally Invasive Therapy at Massachusetts General, and Dr. John Kaufman, Interventional Radiologist and Assistant Professor of Radiology at Harvard Medical School.